State of California

THE RESOURCES AGENCY

Department of Water Resources

BULLETIN No. 164

# TEHACHAPI CROSSING DESIGN STUDIES

## Book III



MAY 1965

HUGO FISHER
*Administrator*
The Resources Agency

EDMUND G. BROWN
*Governor*
State of California

WILLIAM E. WARNE
*Director*
Department of Water Resources

State of California
THE RESOURCES AGENCY
Department of Water Resources

BULLETIN No. 164

# TEHACHAPI CROSSING DESIGN STUDIES

## Book III

MAY 1965

| HUGO FISHER | EDMUND G. BROWN | WILLIAM E. WARNE |
|---|---|---|
| *Administrator* | *Governor* | *Director* |
| The Resources Agency | State of California | Department of Water Resources |

# TEHACHAPI PUMPING PLANT

# COMPARATIVE ANALYSIS OF LIFT CONCEPTS

# PUMPS AND INTERFACE ELEMENTS

VOLUME III

## INVESTIGATION OF HIGH SPEED PUMPING PRACTICE IN EUROPE AND THE UNITED STATES

April 1965

DANIEL, MANN, JOHNSON, & MENDENHALL
Engineering Division
Los Angeles

Associate Consultants
MOTOR-COLUMBUS
Baden/Switzerland

TABLE OF CONTENTS

PART I

## INVESTIGATION OF HIGH HEAD PUMPING PRACTICE IN EUROPE

## PART II

## INVESTIGATION OF

## UNITED STATES PUMPING STATIONS

# PART I

# INVESTIGATION OF HIGH HEAD PUMPING PRACTICE IN EUROPE

## INVESTIGATION OF HIGH HEAD PUMPING PRACTICE IN EUROPE

### 1. INTRODUCTION:

An investigation of high head pumping practice in Europe was conducted during the summer of 1964 by a team, consisting of O. Hartmann, Motor-Columbus, Ltd., Baden, Switzerland, and H. Gartmann, E. Cole and R. Westman, members of the Daniel, Mann, Johnson, & Mendenhall Tehachapi Project staff.

The investigation was made in order to provide more detailed data from various high head pump installations on operating and design experience, particularly with regard to reliability factors, maintenance practices, experience with various construction materials and other pertinent data.

A total in excess of thirty plants were visited, most of them being plants containing pumps, although some water turbine plants having exceptionally high heads per stage and operating with Francis runners were also included. It was felt that experience with wear of runners and seal rings, etc., for the latter could be included in the overall evaluation. Particular attention was paid during the plant visits to the available suction conditions for each pumping unit. Where possible, noise measurements and vibration measurements were obtained, both during normal operation and during shut-down and start-up of the units.

A detailed report, covering each plant visited is incorporated herein. For a detailed evaluation of the survey see comments in Chapter 2, Volume II.

### 2. SUMMARY OF PLANTS VISITED:

A total of twenty-eight pumping plants are included in this report. Placing the plants in approximate categories, all figures referring to the individual pumps, the following gives an indication of the complexity of the installations:

a) Capacities varied from 16.5 cfs to 1161 cfs.
b) Pumping head varied from 200 ft. to 3151 ft.
c) Number of stages in pumps varied from 1 to 9.
d) Pump power rating varied from 6800 HP to 93,400 HP.

e) Operating speeds varied from 214 rpm to 1500 rpm.

f) Specific speed varied from 1120 to 2550.

g) Suction specific speeds varied from 834 to 8460.

Pertinent information which was collected is shown on Plates III, IV and V of this report.

A chart showing in graphical form the comparison of various pertinent parameters is shown on Plate I of this report.

TABLE I

LIST OF PUMPING PLANTS WITH PRINCIPAL OPERATING DATA

(Listed in order of decreasing head)

| Plant No. * | Name | Head Ft. | Cap cfs | Speed rpm | Specific Speed Ns |
|---|---|---|---|---|---|
| 5 | Lunersee | 3151 | 144 | 750 | 1500 |
| 11 | Tremogio | 2953 | 16.5 | 1000 | 1120 |
| 17 | Motec | 2065 | 115 | 750 | 1270 |
| 22 | Ponale | 1903 | 130 | 500 | 1180 |
| 25 | Tierfehd | 1755 | 97 | 1000 | 1750 |
| 15 I | Z'Mutt | 1541 | 194 | 1500 | 2140 |
| 7 | Ferrera | 1529 | 141 | 750 | 1295 |
| 24 I | Etzel | 1475 | 92 | 500 | 1428 |
| 24 II | Etzel | 1475 | 113 | 500 | 1581 |
| 21 | Villa Gargnano | 1380 | 487 | 600 | 1479 |
| 12 | Limberg | 1349 | 474 | 500 | 1230 |
| 14 | Grimsel | 1310 | 141 | 1000 | 1375 |
| 9 | Peccia | 1230 | 83.7 | 1000 | 1568 |
| 15 II | Z'Mutt | 1200 | 113 | 1500 | 1980 |
| 4 | Rodund | 1140 | 353 | 500 | 1200 |
| 26 I | Sipplingen | 1035 | 150 | 998 | 1430 |
| 26 II | Sipplingen | 1035 | 75 | 1490 | 1532 |
| 29 | Arolla | 1017 | 148 | 1500 | 2550 |
| 23 | Ffestiniog | 1000 | 745 | 428 | 1650 |
| 20 | Vianden | 879 | 803 | 428 | 1898 |
| 32 | Herva | 868 | 357 | 500 | 1480 |
| 2 | Witznau | 838 | 353 | 333 | 1430 |
| 30 | Ferpecle | 700 | 99 | 1500 | 2340 |
| 16 | Stafel | 684 | 116 | 1500 | 1805 |
| 1 | Häusern | 689 | 353 | 333 | 1640 |
| 28 | Prov videnza | 565 | 790 | 500 | 2010 |
| 3 | Waldshut | 541 | 353 | 250 | 1490 |
| 19 | Herdecke | 508 | 494 | 300 | 1564 |
| 27 | Cotilia | 492 | 495 | 375 | 1210 |
| 31 | Geesthacht | 250 | 1161 | 214 | 1935 |
| 13 | Moll | 200 | 282 | 495 | 2410 |

*Reference number, signifying order that plants were inspected.

PLANT NAME: HAUSERN

REPORT NO.: 1

| | |
|---|---|
| LOCATION-ALTITUDE: | GERMANY - BLACK FOREST - 2370' |
| OWNER: | Schluchseewerk, A. G. |
| ADDRESS: | Freiburg, Germany |
| TYPE OF PLANT: | Surface |
| SERVICE: | Pump Storage - Generation |
| TYPE OF WATER: | Good - Lake and River |
| UNITS INSTALLED: | Four vertical 2-stage, single-suction pumps with turbines and generators. |
| HORSEPOWER: | 4 x 34,900 (333-1/3 RPM) |
| CFS: | 4 x 353 |
| STATIC HEAD: | 680' |
| PLANT STARTED: | 1933 |
| VISITED BY: | Gartmann - Hartmann |
| DATE: | June 24, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Peter Röllgen, Director<br>Emil Schmidt, Chief Engineer<br>Ernst Lüber, Engineer<br>Klaus Döring, Engineer |
| REMARKS: | This plant takes water from Schluchsee and returns it thereto. Works in conjunction with Witznau and Waldshut. |

PUMPS:

| | |
|---|---|
| TYPE: | Vertical - 2-stage, single suction |
| MANUFACTURER: | two Voith; two Escher Wyss |
| SIZE DISCHARGE: | 55" |
| SIZE SUCTION: | - |
| RPM: | 333-1/3 |
| CFS: | 353 |
| HEAD: | 690' |
| H.P. REQUIRED: | 31,500 |
| N s.: | 1640 |
| INSTALLED: | 1933 |
| HRS. OF OPERATION | 59,000 - 77,000 (to 12/31/63) as a pump |
| MIN. SUBMERGENCE: | 24.6' (rarely) |
| NORMAL SUBMERGENCE: | 37.8' |
| MAX. SUBMERGENCE: | 5. ' |
| REMARKS: | - |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | (Model ratio 7. 38) |
| MODEL ACTUAL: | 84. 0 |
| PROTOTYPE-GUARANTEED: | - |
| PROTOTYPE-ACTUAL: | 87. 8 |
| METHOD OF TEST: | 21 current meters in discharge |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 55" |
| DIAMETER IMPELLER: | 100" |
| DIAMETER EYE: | 63" |
| DIAMETER SHAFT: | 21. 6" - 23. 6" (flange) 19. 7" at Stuffing box |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | "Steel Bronze" to 1955 - 1st stage now 13% Cr. |
| MATERIAL IMPELLER RINGS: | None until 1955 - now stainless steel. |
| MATERIAL-CASING RINGS: | Cast Steel - Babbitt |
| RADIAL CLEARANCE: | 0. 2 mm (inc. to . 5 to . 7 mm in 10 yrs. ) |
| MATERIAL BALANCING RINGS: | Sta. cast steel; Rot. 13% Cr. (1 mm clearance - replaced at 1. 5 mm) |
| MATERIAL INTERSTAGE SEAL: | Cast Steel-Babbitt |
| RADIAL CLEARANCE: | 0. 008" (increased to 0. 020-0. 028 in 10 years) |
| MATERIAL DIFFUSER: | - |
| BEARING: | 18. 9" (Upper) |
| THRUST BEARING: | Michel - 13. 6" I. D. |

| | |
|---|---|
| TYPE OF PACKING: | - |
| MATERIAL OF PACKING: | Four Carbon Rings |
| MATERIAL OF SLEEVE: | Cast Iron (Orig. bronze corroded badly) |
| CLEARANCE: | - |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical - Synchronous |
| MANUFACTURER: | Two Brown Boveri; Two Siemans |
| H.P.: | 34,900 |
| R.P.M.: | 333-1/3 |
| VOLTAGE: | 10,500 |
| STARTING: | Brought up to speed with Torque converter against closed valve. |
| REMARKS: | - |

TURBINE:

| | |
|---|---|
| TYPE: | Francis |
| MFG.: | Two Voith |
| HEAD: | 456' - 689' |
| R.P.M.: | 333-1/3 |
| H.P.: | 33,800 kw |
| REMARKS: | - |

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | Flapper - Square C.S. |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | Locked open - Used for maintenance only. Hyd. Operated. |

DISCHARGE:

| | | |
|---|---|---|
| TYPE: | Needle | |
| MANUFACTURER: | Two Voith; Two Escher Wyss | |
| SIZE: | 55" | |
| OPERATION: | Voith | Escher Wyss |
| OPENING: | Oil | Oil |
| CLOSING: | Oil | Water |
| TIME OF CLOSING: | | |
| NORMAL: | 15 - 18 seconds | |
| EMERGENCY: | - | |
| REMARKS: | - | |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Surface |
| NO. & SIZE: | Two - 8.2' Dia. |
| LENGTH: | Tunnel 13.45' dia. |

MATERIAL: -

TYPE OF UPPER GATE: -

SURGE TANK: At upper end of Penstock - 10 m dia. 75 m Vertical into 28 m dia. tanks.

REMARKS: -

WATER QUALITY:

GENERAL: Good - 11 PPM $CO_2$

Ph: -

HARDNESS: -

REMARKS: Rhine River and/or Schluchsee Water

MAINTENANCE AND OPERATION:

OPERATING SCHEDULE: Night and noon off peak

STARTS/DAY: 2 ±

| HOURS OF OPERATION: | A1 | A2 | B1 | B2 |
|---|---|---|---|---|
| Generating (Until 12/31/63) | 61,561 | 51,374 | 38,466 | 60,739 |
| Pumping | 77,434 | 70,513 | 59,368 | 71,464 |
| Condensing | 78,342 | 74,669 | 53,713 | 65,884 |

UNPLANNED OUTAGES: 2

CAUSE: 1) Impeller bolt; 2) Diaphragm

INSPECTION SCHEDULE: Once per year

TIME REQUIRED: -

OVERHAUL SCHEDULE: Every 10 years

TIME REQUIRED: 9 - 10 weeks

IMPELLER CAVITATION: Yes - after 10,000 Hrs. - Impeller welded with 13% cr

SEAL RING WEAR: . 2 to . 3 mm in 20-25, 000 hrs.

NOISE LEVEL-START: 98 DB

NOISE LEVEL-RUN: 93 DB

VIBRATION: -

REMARKS: Bronze parts did not stand up. Replaced by 13% Cr. steel after 22 years of operation. No trouble since. Impeller showed cavitation and/or erosion after 10, 000 hrs. Welded with 13% chrome in 1955. Polished once per year since.

OPERATING HOURS FOR PLANT HÄUSERN
SINCE LAST OVERHAUL UP TO DECEMBER 31, 1963

| Unit | Reason for Overhaul | From | To | Hours | For |
|---|---|---|---|---|---|
| AI | Rebuilding Pump | 10/1/55 | 12/31/63 | 19, 175 | Pump |
| A1 | Rewinding Generator | 6/29/59 | 12/31/63 | 28, 007 | Generator |
| A2 | Rebuilding Pump | 11/8/57 | 12/31/63 | 14, 611 | Pump |
| A2 | Turbine Runner | 9/23/57 | 12/31/63 | 12, 771 | Turbine |
| A2 | Rewinding Generator | 9/23/57 | 12/31/63 | 43, 895 | Generator |
| B1 | Rewinding Generator | 8/25/54 | 12/31/63 | 57, 770 | Generator |
| B1 | Same - for Turbine Operation Only | 8/25/54 | 12/31/63 | 14, 529 | Turbine |
| B1 | Rebuilding Pump | 10/5/58 | 12/31/63 | 9, 012 | Pump |
| B1 | Turbine Runner | 9/29/59 | 12/31/63 | 6, 635 | Turbine |
| B2 | Rebuilding Pump | 10/1/56 | 12/31/63 | 14, 457 | Pump |
| B2 | Turbine Runner | 11/3/60 | 12/31/63 | 5, 081 | Turbine |
| B2 | Rewinding Generator | 11/3/60 | 12/31/63 | 17, 291 | Generator |

## GENERAL REMARKS

When the 4 units were installed in 1931, they were designed for a reduced capacity of 7.5 m3/s each and were equipped with a spherical valve in the discharge and movable guide vanes in the second stage. In 1955/58, the units were rebuilt for the increased rating of 10.0 m3/s, or 353 CFS, with fixed guide vanes and the spherical valve was replaced by a needle valve in the pump discharge.

The original impellers were made of "steel-bronze', which is a bronze containing an undetermined amount of steel. Cavitation was experienced on the first stage impellers and during the changeover in 1955 the material of the first stage impellers was changed to 13% chrome, 1% nickel, while the material for the second stage was changed to cast steel, and no cavitation has been experienced since that time. They do find it desirable to polish the vane inlet of the suction impeller about once a year and this work is done without dismantling the unit.

As will be seen from later reports, practically all large pumps which we have visited in Europe are equipped with carbon ring seals at the packing. In general, these seals have been the source of some difficulty. This particular plant handles extremely clean water and no special effort must be made to supply filtered sealing water to the carbon packing. However, at first the shaft sleeves under the packing were made of brass and showed rapid wear or corrosion. During the war, when brass was at a premium, they were replaced with cast iron sleeves as a substitute and surprisingly, the cast iron gave excellent results and is still used today. These units are two-stage, single flow pumps, equipped with a labyrinth type hydraulic balancing arrangement on the discharge side, the stationary ring being cast steel and the rotating ring being made of 13% chrome steel. To prevent excessive pressure on the discharge packing, this end is equipped with a small centrifugal impeller next to the packing which reduces the pressure on the packing to the same value as for that on the suction side.

The interstage seal in each pump is made of steel for the rotating part, running against a babbitt lined bushing. The original radial clearance was .2 mm or .008". The wear in 10 years increased this clearance to .5 - .7 mm or .020 - .028". It is their present practice to overhaul the units once every 10 years at which time the wearing parts like shaft seals and interstage seals are replaced.

They estimate that each of these pumps has as much as 700 starts per year. They have only had two unscheduled shut-downs due to pump problems. One was due to a bolt coming loose on the impeller fastening and the second was due to a casting failure of a diaphragm on the discharge side of the pump.

The pumps can be disassembled from the suction or lower end without dismantling any of the other parts of the complete shaft assembly consisting of generator, turbine and torque converter. The pump casings are encased in concrete. No provision is made for any expansion joints in either the suction piping or the discharge piping.

The pumps are started submerged, being brought up to speed by means of the torque converter. We asked Mr. Schmidt for his opinion regarding the respective merits of spherical valves versus needle valves in the pump discharge. He indicated that it would be his preference to use spherical valves on new installations, both due to their smaller cost and simpler operating control.

Mr. Schmidt also stated that for vertical machines of this type he would estimate a complete overhaul to take from 9 - 10 weeks while for a similar horizontal machine, this time would be reduced to 8 weeks. They further estimate that in order to dismantle the first stage only, they require 3 to 4 weeks time. In each case, this would require the service of approximately 8 men working on a 45-hour week.

Noise readings taken at this plant during a changeover from turbine operation to pump operation were as follows:

| | C-Scale |
|---|---|
| Turbine Operation: | 85 decibel (db) |
| Changeover to pumo peration (valve opening); | 98 db |
| Pump operation | 93 db |

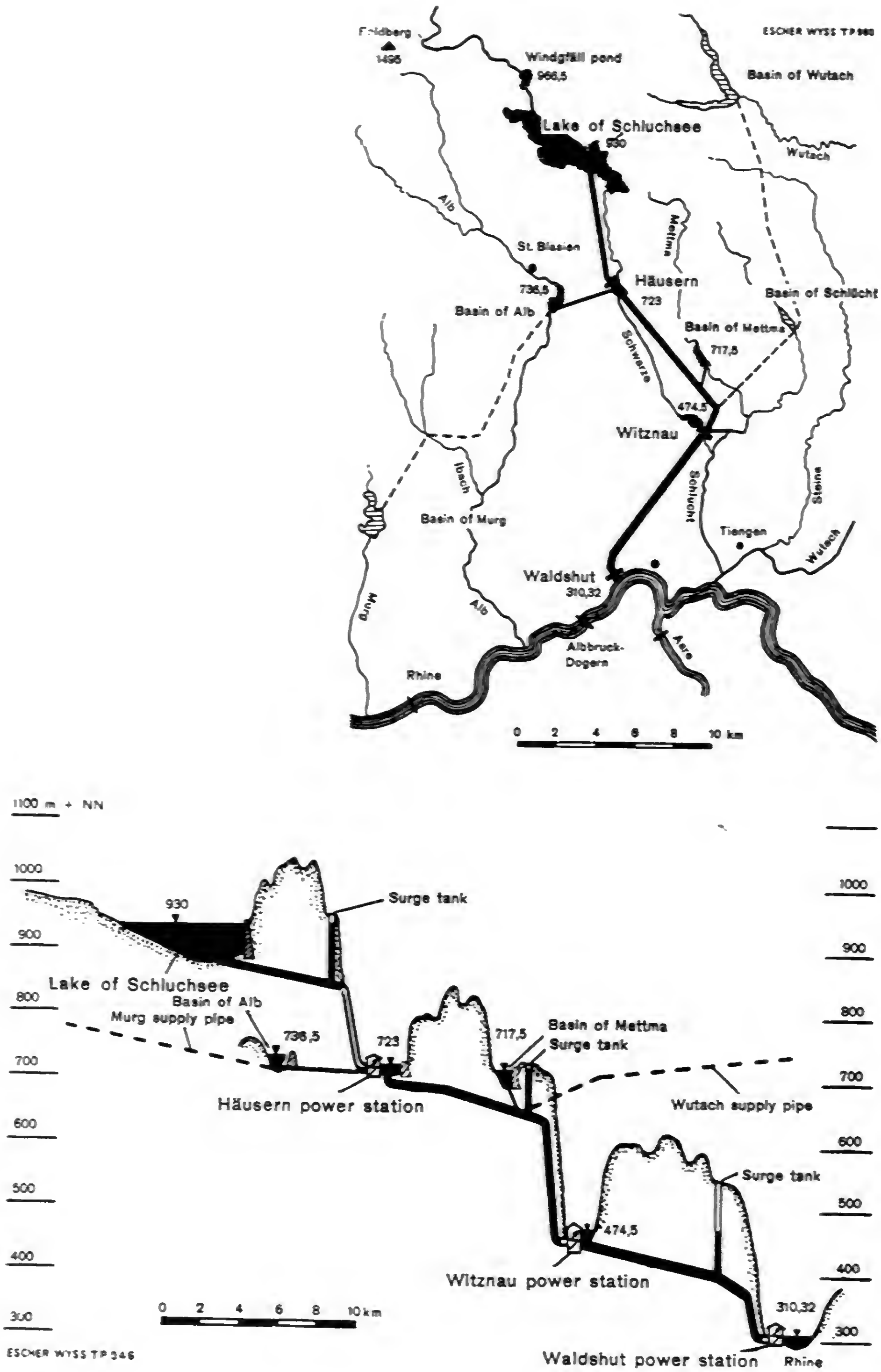



Fig. 1. 1 - Plan and Profile of Schluchsee System

Fig. 1.2 (Gl-7) Häusern Plant and Penstocks

Fig. 1-3 - Operating Floor

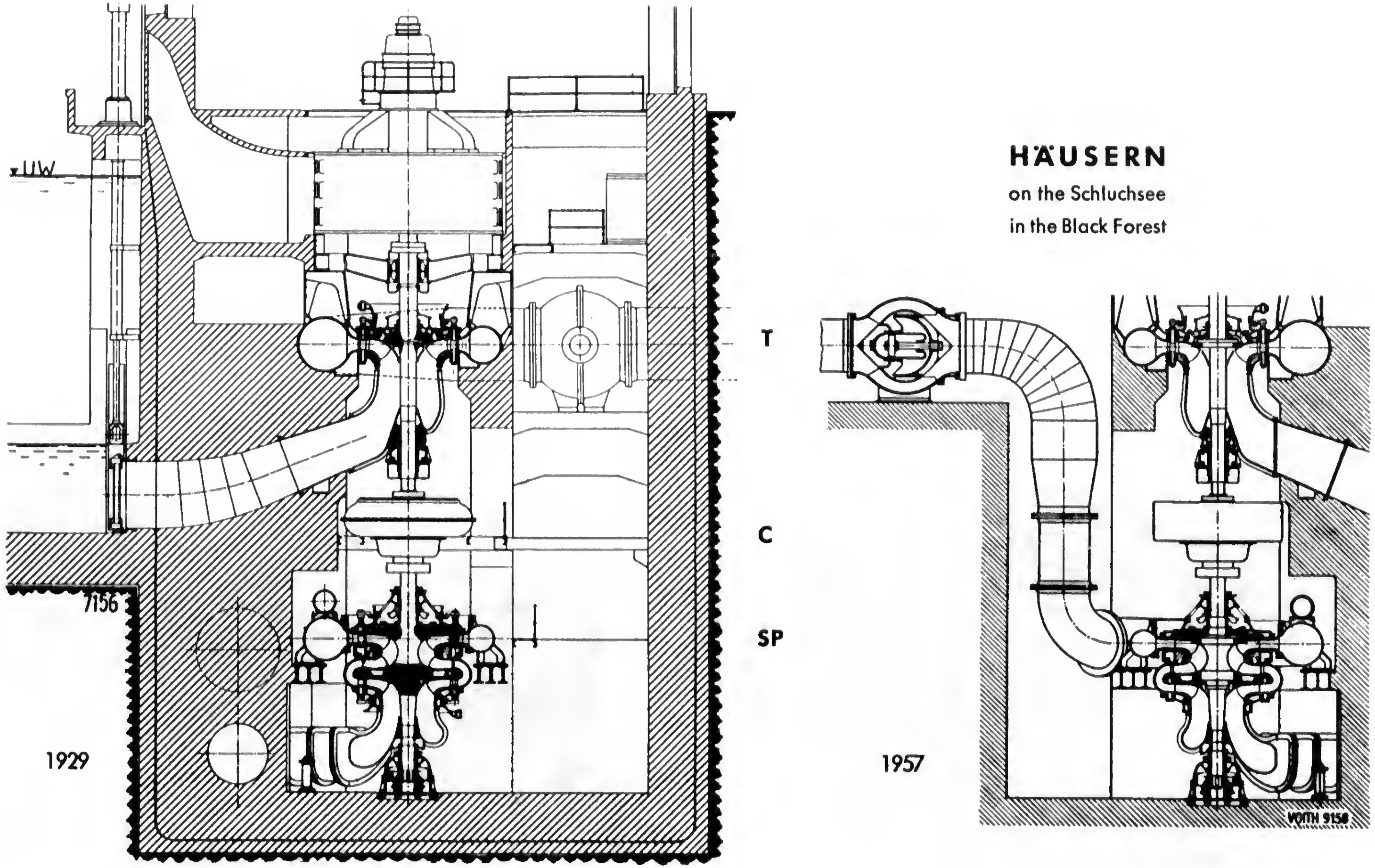



Fig. 1.4 - Cross-section through pumps

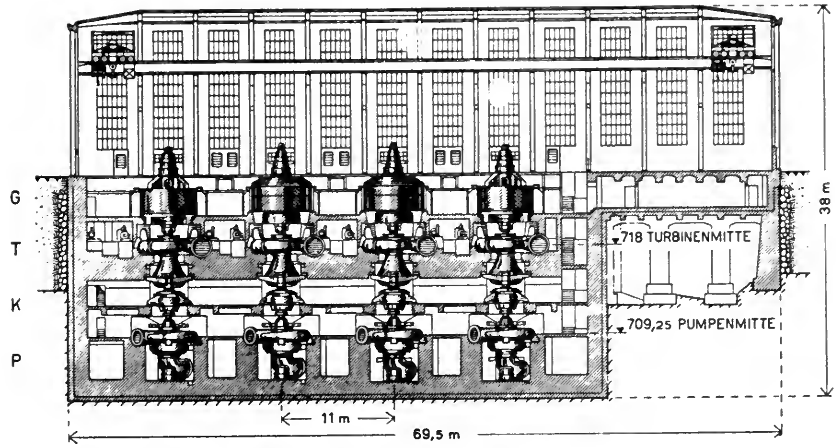


Bild 15 Kraftwerk Häusern, Längenschnitt

Fig. 1.5 - Longitudinal Section of Station

PLANT NAME: WITZNAU

REPORT NO.: 2

| | |
|---|---|
| LOCATION-ALTITUDE: | Black Forest, Germany - 1556' |
| OWNER: | Schluchseewerk, A.G. |
| ADDRESS: | Freiburg, Breisgau, Germany |
| TYPE OF PLANT: | Surface |
| SERVICE | Pump Storage - Power Generation |
| TYPE OF WATER: | Good |
| UNITS INSTALLED: | Four 2-stage, single-flow, vertical pumps with Turbines and Generators |
| HORSEPOWER: | 42,800 |
| CFS: | 353 |
| STATIC HEAD: | 816' |
| PLANT STARTED: | 1946 |
| VISITED BY: | Gartmann-Hartmann |
| DATE: | June 24, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Peter Röllgen, Director - Op. Dept.<br>Emil Schmidt, Chief Engineer<br>Ernst Lüber, Engineer<br>Klaus Döring, Engineer |
| REMARKS: | This plant receives water from the afterbay of the Hausern plant, and returns it thereto. Operates in conjunction with Hausern and Waldshut. |

## PUMPS:

| | |
|---|---|
| TYPE: | - Two-stage, single-suction, Vertical Split Case |
| MANUFACTURER: | Escher-Wyss |
| SIZE DISCHARGE: | 55" |
| SIZE SUCTION: | - |
| RPM: | 333-1/3 |
| CFS: | 282 - 370 |
| HEAD: | 895' - 815 |
| H.P. REQUIRED: | 34,600 - 39,100 |
| N s.: | 1220 - 1530 |
| INSTALLED: | 1943 |
| HRS. OF OPERATION | 27,000 to 40,000 (until end of 1963) as pumps |
| MIN. SUBMERGENCE: | 37' |
| NORMAL SUBMERGENCE: | 49' |
| MAX. SUBMERGENCE: | 65' |
| REMARKS: | Pumps started with impulse turbine, unwatered. Air let out at bottom, after unit synchronized and water enters through the discharge. |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | 83 |
| PROTOTYPE-GUARANTEED: | - |
| PROTOTYPE-ACTUAL: | 87.5 |
| METHOD OF TEST: | 21 current meters in discharge. |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 55" |
| DIAMETER IMPELLER: | 111" (11 vanes) |
| DIAMETER EYE: | 64" |
| DIAMETER SHAFT: | 21-3/4 - 22" |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | Cast Steel (Two 1st st. changed to 13/1 Cr. in '59-'58) |
| MATERIAL IMPELLER RINGS: | Steel |
| MATERIAL-CASING RINGS: | Steel |
| RADIAL CLEARANCE: | .040" |
| MATERIAL BALANCING RINGS: | - |
| MATERIAL INTERSTAGE SEAL: | - |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | - |
| BEARING: | 22" - Babbitt |
| THRUST BEARING: | Michell - 400 ton |

| | |
|---|---|
| TYPE OF PACKING: | - |
| MATERIAL OF PACKING: | Four carbon rings |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | - |

<u>MOTOR OR GENERATOR:</u>

| | |
|---|---|
| TYPE: | Vertical - Synchronous direct connected Exciter |
| MANUFACTURER: | Brown Boveri (Mannheim) |
| H. P. : | 43, 000 (55, 100 kw) |
| R. P. M. : | 333-1/3 |
| VOLTAGE: | 10, 500 |
| STARTING: | With Impulse Turbine |
| REMARKS: | - |

<u>TURBINE:</u>

| | |
|---|---|
| TYPE: | Vertical - Francis |
| MFG. : | Voith |
| HEAD: | 623' to 853' |
| R. P. M. : | 333-1/3 |
| H. P. : | 74, 000 (55, 100 kw) |
| REMARKS: | Also a synchronizing impulse Turbine and Gear Coupling, by Voith. |

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | Flap Valve |
| MANUFACTURER: | - |
| SIZE: | (Square C. S.) |
| OPERATION: | Hydraulic (Locked open) |

DISCHARGE:

| | |
|---|---|
| TYPE: | Needle |
| MANUFACTURER: | Von Roll |
| SIZE: | 55" |
| OPERATION: | |
| OPENING: | - |
| CLOSING: | - |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | Cast steel with 12% Cr. seat. |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | One - 16.5' |
| LENGTH: | Approx. 9.5 miles |

MATERIAL: -

TYPE OF UPPER GATE: -

SURGE TANK: 12 m stand pipe at midway point, going up 65 m to 49 m dia. reservoir.

REMARKS: See Profile

WATER QUALITY:

GENERAL: Good

Ph: -

HARDNESS: -

REMARKS: Rhine River water and/or water from Schluchsee

MAINTENANCE AND OPERATION:

OPERATING SCHEDULE: Off peak pumping - night and noon.

STARTS/DAY: 2 $\pm$

HOURS OF OPERATION: (Until 12/31/63)

| | A-3 | A-4 | B-3 | B-4 |
|---|---|---|---|---|
| Generation | 43, 344 | 42,685 | 34, 531 | 21,322 |
| Pumping | 39, 936 | 36, 307 | 26, 896 | 27, 248 |
| Condensing | 17, 986 | 20, 756 | 24, 008 | 14, 508 |

CAUSE: -

INSPECTION SCHEDULE: -

TIME REQUIRED: -

OVERHAUL SCHEDULE: -

TIME REQUIRED: -

IMPELLER CAVITATION: -

SEAL RING WEAR: -

NOISE LEVEL-START: 100

NOISE LEVEL-RUN: 93

VIBRATION: -

REMARKS: -

OPERATING HOURS FOR PLANT WITZNAU
SINCE LAST OVERHAUL UP TO DECEMBER 31, 1963

| Unit | Reason for Overhaul | From | To | Hours | For |
|---|---|---|---|---|---|
| A3 | Pump Runner - Welding | 12/1/52 | 12/31/63 | 26,853 | Pump |
| A3 | Rewinding Generator | 5/14/60 | 12/31/63 | 24,929 | Generator |
| A3 | Same - for Turbine Operation only | 5/14/60 | 12/31/63 | 8,314 | Turbine |
| A4 | Pump Runner - Welding | 10/1/53 | 12/31/63 | 24,793 | Pump |
| A4 | Rewinding Generator | 11/27/61 | 12/31/63 | 16,713 | Generator |
| A4 | Same - for Turbine Operation only | 11/27/61 | 12/31/63 | 4.979 | Turbine |
| B3 | New Pump Runner | 12/6/57 | 12/31/63 | 11,147 | Pump |
| B4 | New Pump Runner | 3/12/58 | 12/31/63 | 10,046 | Pump |
| B4 | Repair - Generator and Turbine | 9/11/59 | 12/31/63 | 17,889 | Generator |
| B4 | Turbine | 9/11/59 | 12/31/63 | 6,459 | Turbine |

## GENERAL REMARKS

These units are very similar to the Häusern units. Being installed during the war, the impellers were made of cast steel and again cavitation and wear was experienced on the first stage impellers. On two of the units, the first stage impellers were repaired by welding with 18% chrome, 8% nickel stainless steel. On the other two units, the first stage impellers were replaced in 1957, using 13% chrome, 1% nickel stainless steel.

These units are started dewatered with a small impulse turbine incorporated in the unit assembly. Some difficulty was experienced on these units originally during the changeover from air operation to pump operation. Instead of exhausting the air from the top, it was found to be advantageous to admit water from the top of the pump case and the air expelled through a control valve mounted on the pump suction volute. Seal water is supplied to the packing and to the internal wearing rings, etc., for the dry start, the seal water being supplied from the penstock.

The noise readings during the changeover from turbine operation to pump operation were as follows:

| | C-Scale |
|---|---|
| Turbine operation: | 92 db |
| Changeover to pumping: | 100 db |
| Pump operation: | 93 db |

Pictures on the following pages show various details of this station.

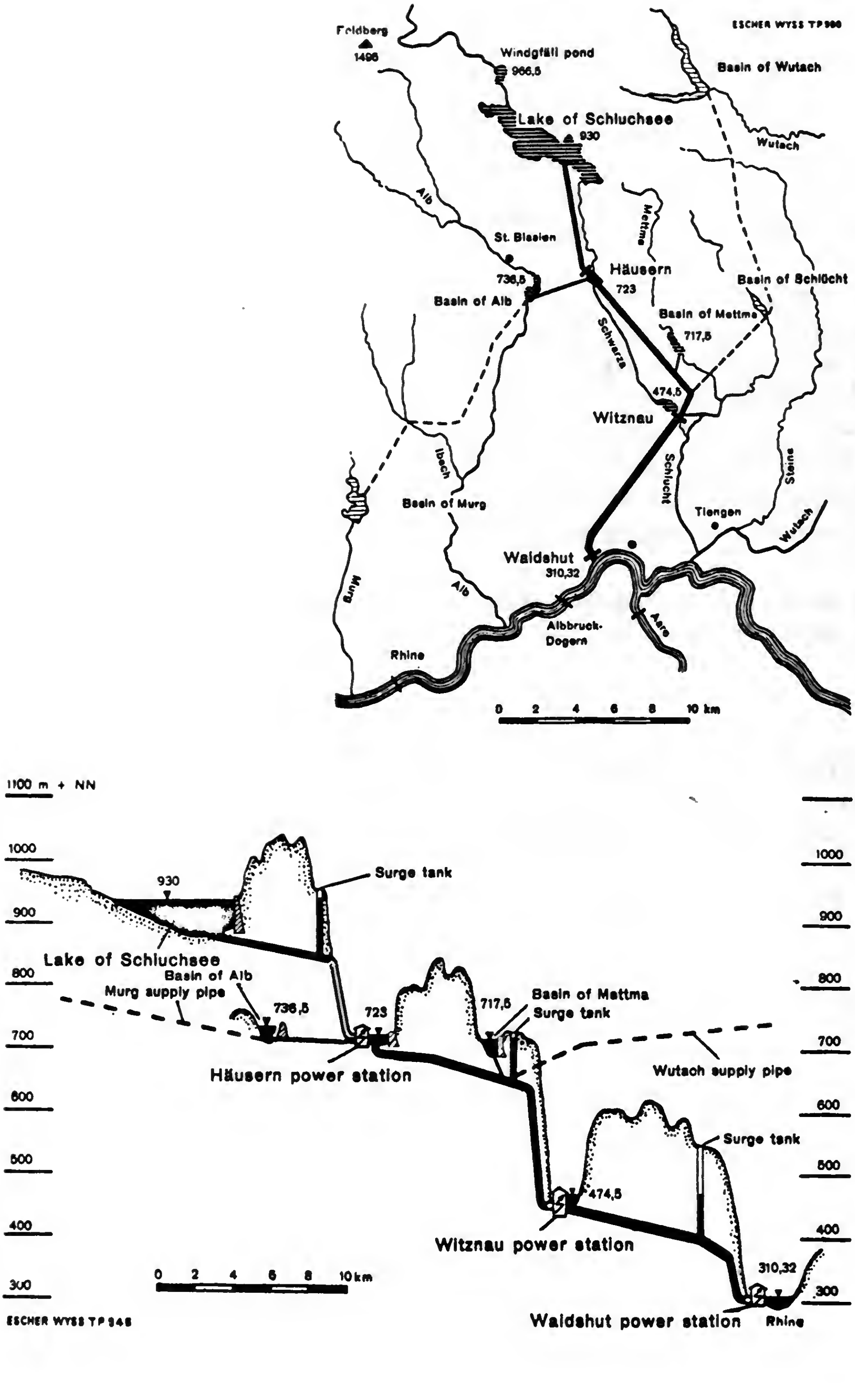



Fig. 2.1 - Location and Profile of Schluchsee System

Fig. 2. 2 View of Station

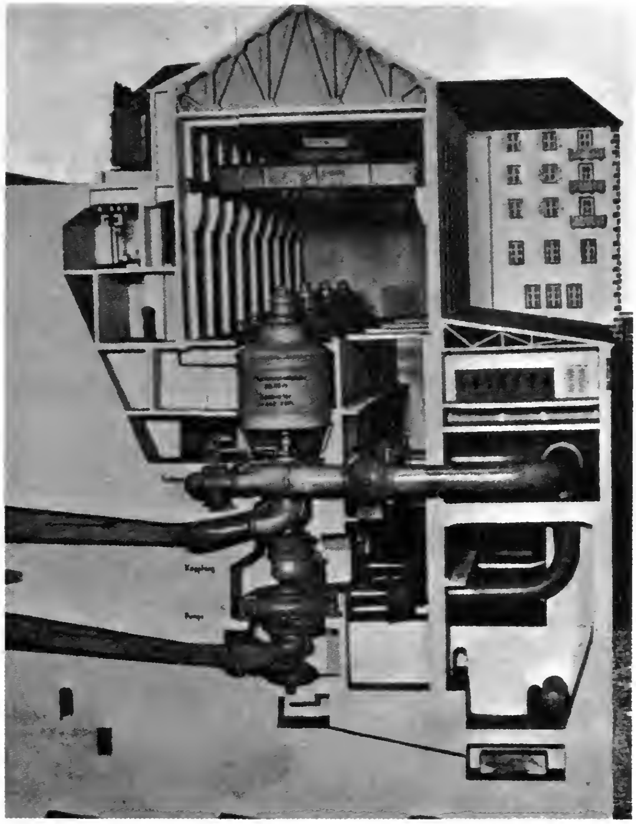


Fig. 2. 3 - Model of Witznau Plant

Fig. 2.4 (Gl-15) Main Operating Floor

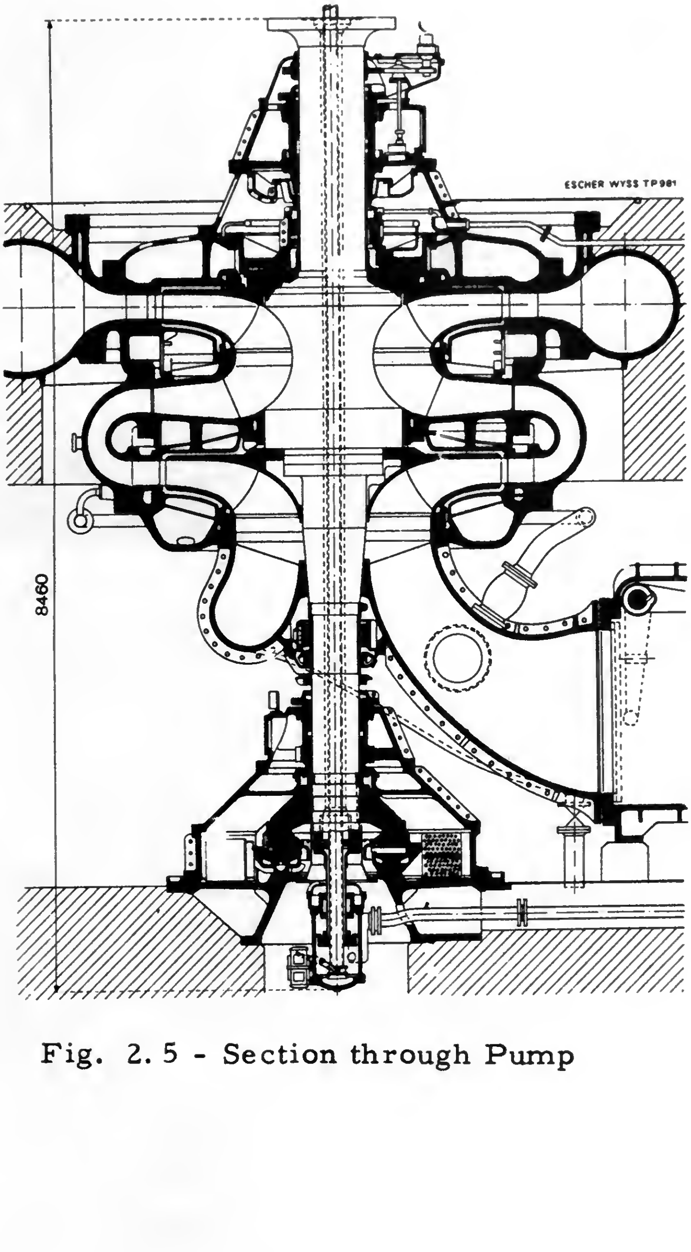



Fig. 2. 5 - Section through Pump

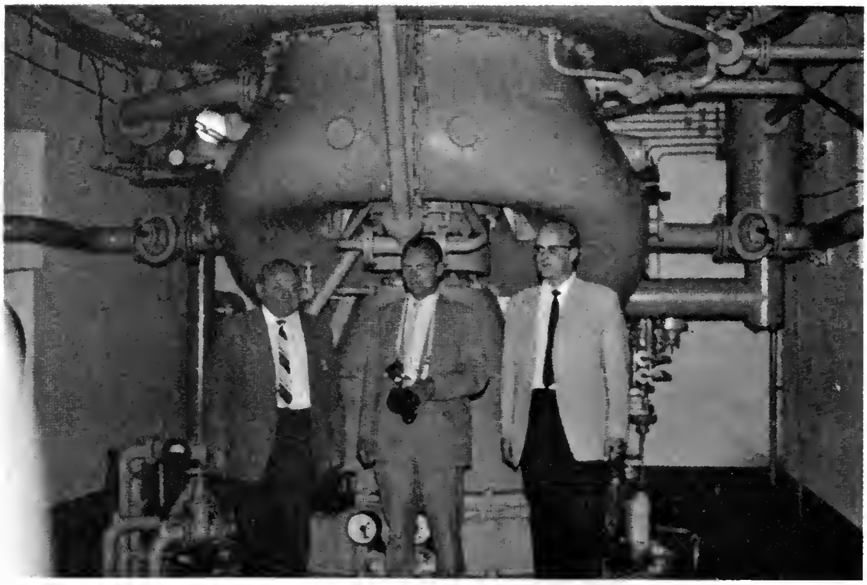


Fig. 2.6 (Gl-12) Pump Floor Showing Inlet Volute

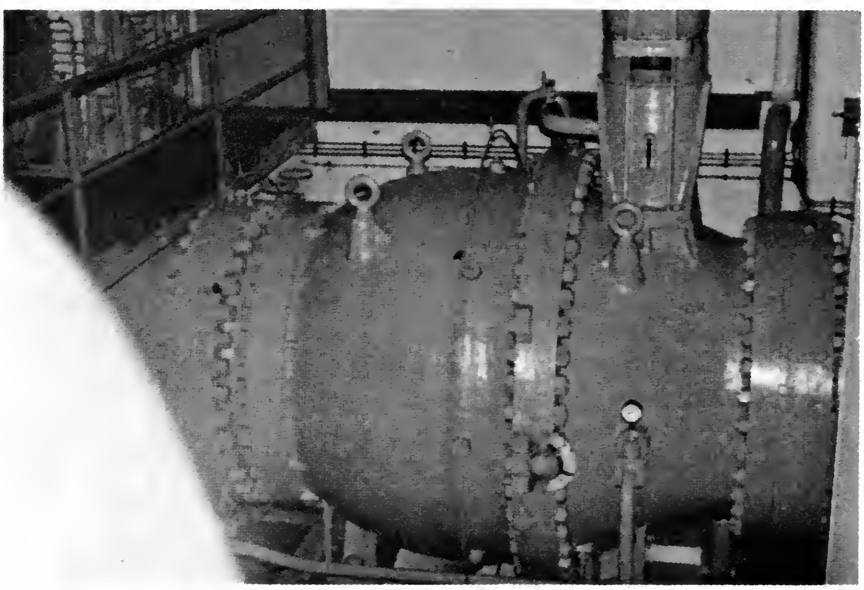


Fig. 2.7 (Gl-11) Needle Valve for Pump Discharge

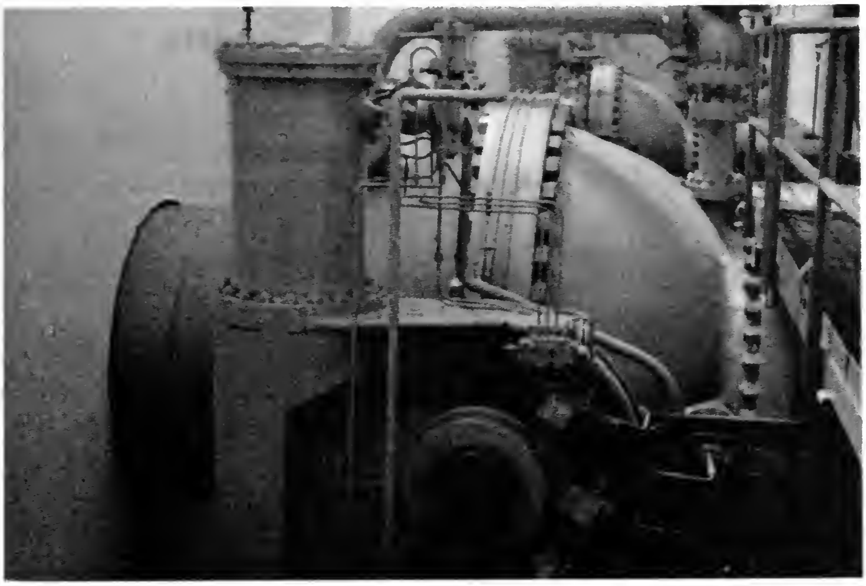


Fig. 2.8 (G1-10) Spherical Valve for Turbine

PLANT NAME: WALDSHUT

REPORT NO.: 3

| | |
|---|---|
| LOCATION-ALTITUDE: | Southern Germany - on the Rhine - 1020' |
| OWNER: | Schluchseewerk A. G. |
| ADDRESS: | Freiburg, Breisgau, Germany |
| TYPE OF PLANT: | Surface |
| SERVICE | Pump Storage - Power Generation |
| TYPE OF WATER: | - |
| UNITS INSTALLED: | Four - 2-stage single flow, horizontal pumps, Motor Generator and Turbine |
| HORSEPOWER: | 26, 800 (250 RPM) |
| CFS: | 353 |
| STATIC HEAD: | 540' |
| PLANT STARTED: | 1951 |
| VISITED BY: | Gartmann - Hartmann |
| DATE: | June 25, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Mr. Peter Röllgen, Director Op. Dept.<br>Mr. Emil Schmidt, Chief Engineer<br>Mr. Ernst Lüber, Engineer<br>Mr. Klaus Döring, Engineer |
| REMARKS: | One of the three plants of the Schluchsee System. This Plant, located on the Rhine, is the lower of three plants supplied by the Schluch Lake in the Black Forest. |

PUMPS:

| | |
|---|---|
| TYPE: | Two-stage, single suction |
| MANUFACTURER: | Voith |
| SIZE DISCHARGE: | 55" (1400 mm) |
| SIZE SUCTION: | - |
| RPM: | 250 |
| CFS: | 353 |
| HEAD: | 541 |
| H.P. REQUIRED: | 24, 250 |
| N s.: | 1490 |
| INSTALLED: | 1951 |

| HRS. OF OPERATION | A-5 | A-6 | B-5 | (June 1963) B-6 |
|---|---|---|---|---|
| Generation | 25, 564 | 23, 946 | 21, 818 | 17, 479 |
| Pumping | 27, 333 | 28, 360 | 24, 583 | 23, 819 |
| As Syn. Cond. | 22, 996 | 28, 314 | 18, 269 | 14, 574 |

| | |
|---|---|
| MIN. SUBMERGENCE: | - 1.6 |
| NORMAL SUBMERGENCE: | 0 |
| MAX. SUBMERGENCE: | - |
| REMARKS: | - |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | - |
| PROTOTYPE-GUARANTEED: | - |
| PROTOTYPE-ACTUAL: | 89. 3 |
| METHOD OF TEST: | - |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 55" (1400 mm) |
| DIAMETER IMPELLER: | - |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 21. 7" |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | Steel with stainless overlay |
| MATERIAL IMPELLER RINGS: | - |
| MATERIAL-CASING RINGS: | - |
| RADIAL CLEARANCE: | 1 mm |
| MATERIAL BALANCING RINGS: | None |
| MATERIAL INTERSTAGE SEAL: | - |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | - |
| BEARING: | - |
| THRUST BEARING: | - |

| | |
|---|---|
| TYPE OF PACKING: | - |
| MATERIAL OF PACKING: | Babbitt |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | 0.2 - 0.3 mm |
| REMARKS: | Due to casting error, one inlet received 1/3 more water than the other, resulting in cavitation. Corrected by plating. |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Horizontal - Synchronous |
| MANUFACTURER: | Siemens Schuckert |
| H. P.: | 59,000 (44,100 kw) |
| R. P. M.: | 250 |
| VOLTAGE: | 10,500 |
| STARTING: | Pump dewatered - Coupling engaged. |
| REMARKS: | - |

TURBINE:

| | |
|---|---|
| TYPE: | Horizontal - Francis |
| MFG.: | Voith |
| HEAD: | 379' - 469' |
| R. P. M.: | 250 |
| H. P.: | 59,000 (44,100 kw) |
| REMARKS: | - |

## VALVES:

### INTAKE:

| | |
|---|---|
| TYPE: | Roller Gate & Butterfly Valves |
| MANUFACTURER: | Voith |
| SIZE: | One 13' - 7" x 17' - 4" gate and Two 14' - 9" BF Valves |
| OPERATION: | - |

### DISCHARGE:

| | |
|---|---|
| TYPE: | Needle |
| MANUFACTURER: | Voith |
| SIZE: | 4' - 7" (1400 mm) |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | - |

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | One - 19.65' (6000 mm) |
| LENGTH: | 31,000 ft. |

| | |
|---|---|
| MATERIAL: | - |
| TYPE OF UPPER GATE: | - |
| SURGE TANK: | 3550' from pump - 46' dia. 540' high. |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Good |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | Clear - Free from sand |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | Pumping nightly, off peak daily plus noon-time off peak. |
| STARTS/DAY: | Two |
| HOURS OF OPERATION: | Pumps 23,000 to 29,000 (see next page) |
| UNPLANNED OUTAGES: | - |
| CAUSE: | - |
| INSPECTION SCHEDULE: | - |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | - |
| TIME REQUIRED: | Approx. 8 weeks |
| IMPELLER CAVITATION: | Yes - First stage impellers overlayed with chromium. |

SEAL RING WEAR: -

NOISE LEVEL-START: 105 db

NOISE LEVEL-RUN: 95 db

VIBRATION: .0015" (during start

REMARKS:

OPERATING HOURS FOR PLANT WALDSHUT
SINCE LAST OVERHAUL UP TO DECEMBER 31, 1963

| Unit | Reason for Overhaul | From | To | Hours | For |
|---|---|---|---|---|---|
| A5 | Pump and Coupling Overhaul | 4/14/58 | 12/31/63 | 14,096 | Pump |
| A5 | General Overhaul of Turbine | 5/1/56 | 12/31/63 | 16,597 | Turbine |
| A6 | Pump and Coupling Overhaul | 6/26/58 | 12/31/63 | 13,195 | Pump |
| A6 | General Overhaul of Turbine | 4/5/59 | 12/31/63 | 9,856 | Turbine |
| B5 | Pump and Coupling Overhaul | 11/5/59 | 12/31/63 | 6,546 | Pump |
| B5 | General Overhaul of Turbine | 3/6/57 | 12/31/63 | 13,499 | Turbine |
| B6 | Pump and Coupling Overhaul | 2/26/58 | 12/31/63 | 11,704 | Pump |
| B6 | General Overhaul of Turbine | 3/21/57 | 12/31/63 | 9,617 | Turbine |

## GENERAL REMARKS

These are horizontal units and the pump centerline is placed approximately at the average level of the Rhein River from which the pumps take their suction. Each pump is started dewatered by a Pelton type turbine and, after coming up to speed, is coupled and primed with a water operated ejector system.

They were placed in operation in 1951, and were equipped with cast steel impellers. Considerable cavitation has been experienced at this station in the first stage impellers. This, in part, is due to the fact that a casting error was made by the foundry during their manufacture and it has been necessary to repair the suction impeller by overlaying the damaged areas with stainless steel every one or two years.

These units operate under inlet conditions of zero submergence and the suction specific speed is 7,650. As this is close to the maximum safe value based on present experience, the problems experienced are probably due to a combination of casting errors and relatively low available submergence.

The noise readings during the changeover from turbine operation to pump operation were as follows:

| | C-Scale |
|---|---|
| For turbine operation: | 92 db |
| For pump operation: | 95 db |
| During the changeover to pumping: | 105 db |

Vibration readings were also taken and showed a maximum displacement of .0015" during the changeover from turbine to pump operation.

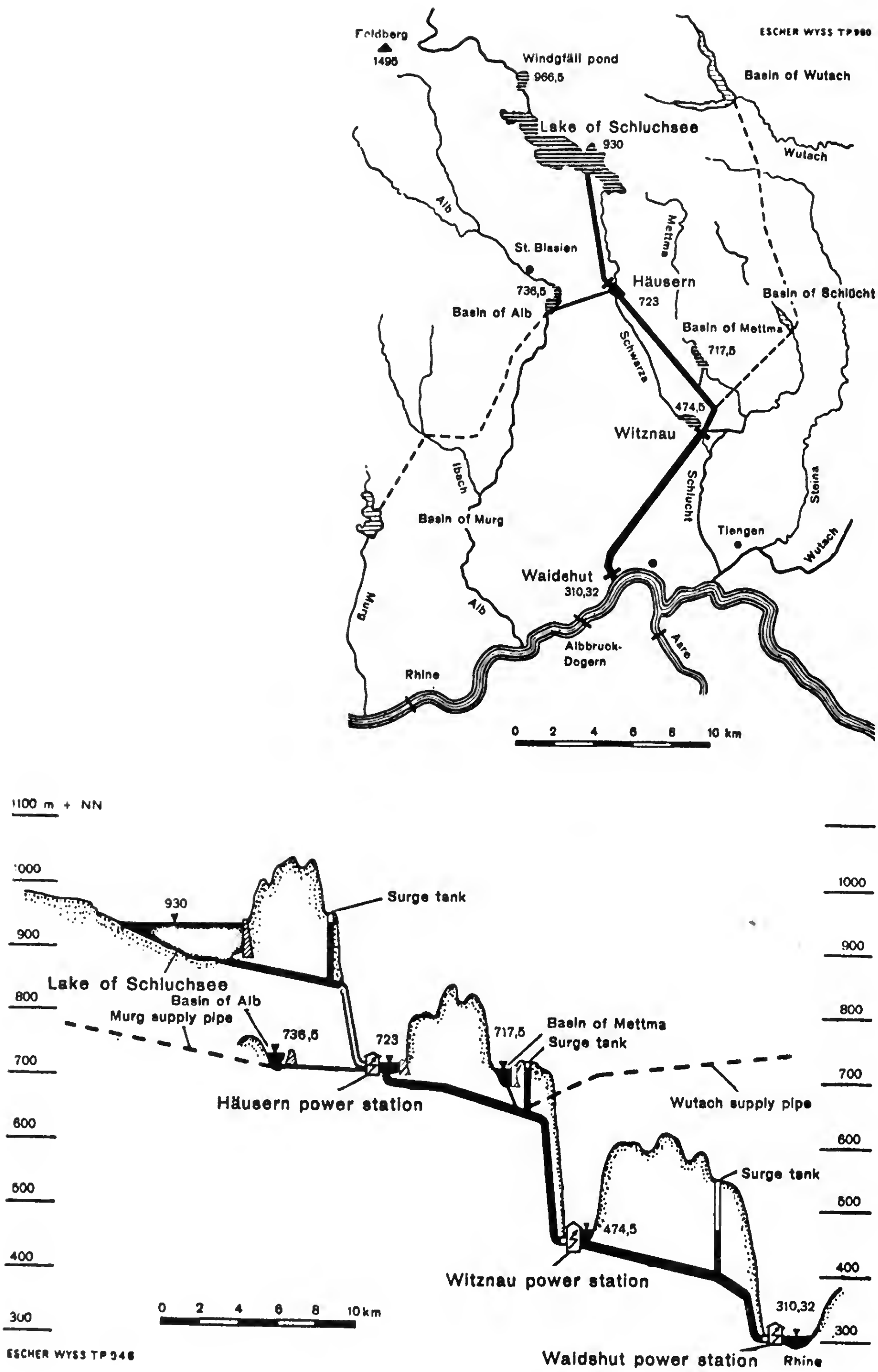



Fig. 3.1 - Plan and Profile of Schluchsee System

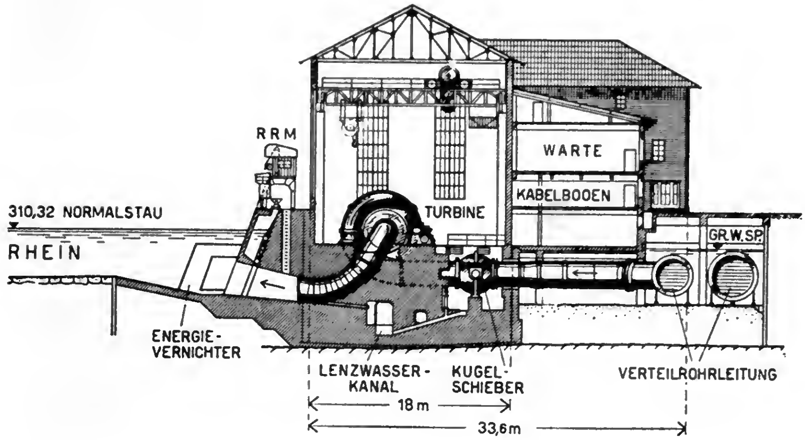



Fig. 3.2 - Section through Plant

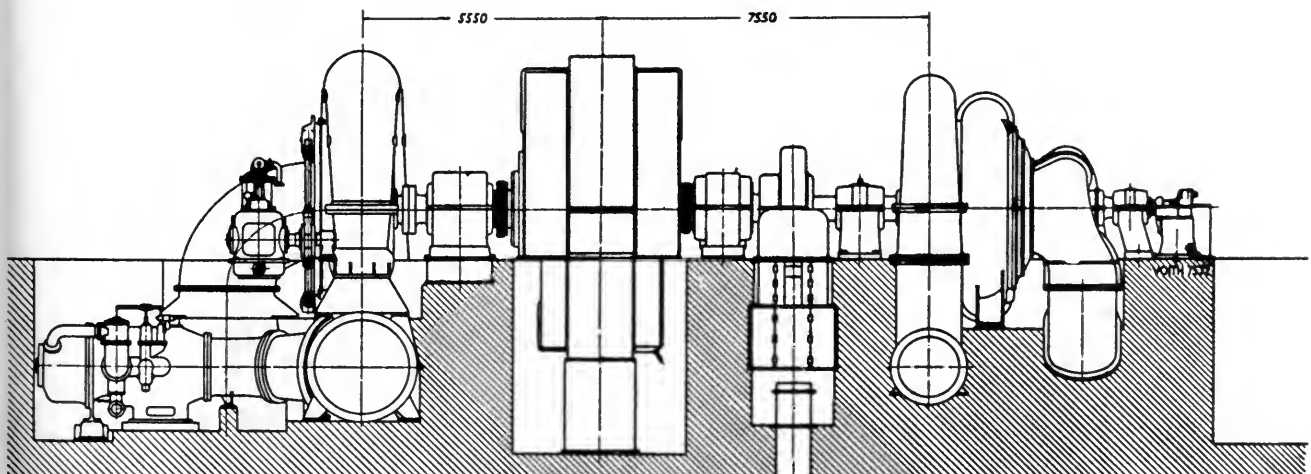



Fig. 3.3 - Section showing arrangement

Fig. 3.4 (G1-16) View of main operating floor

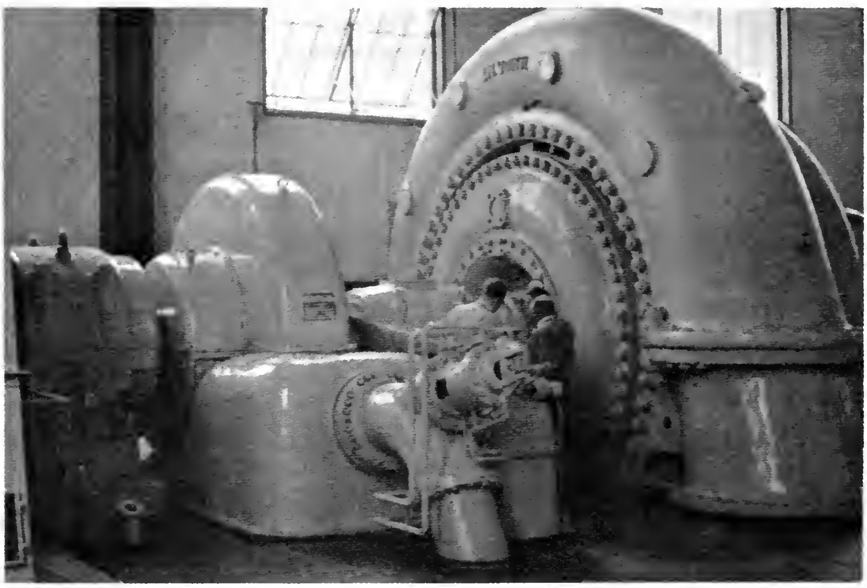


Fig. 3.5 (G1-17) Close-up of pump, starting Turbines & Pump Coupling

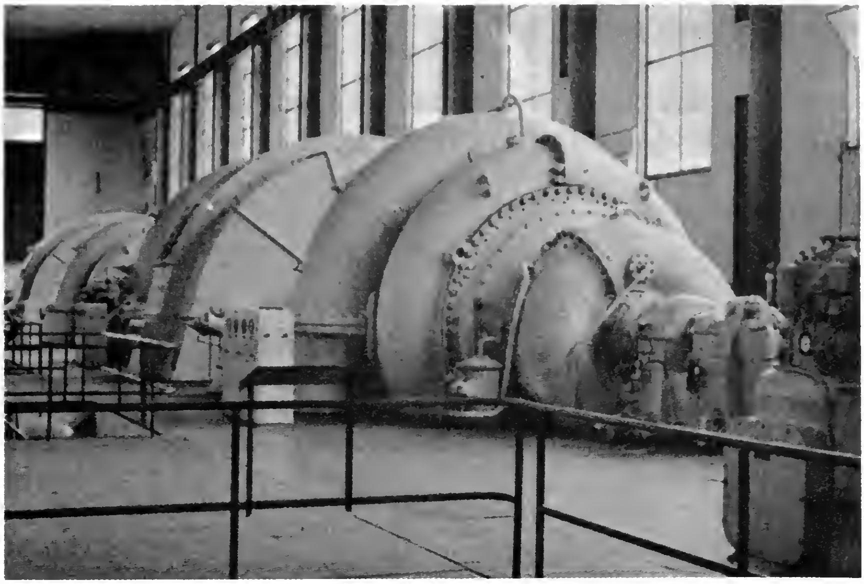


Fig. 3.6 (Gl-18) View of unit from Turbine end

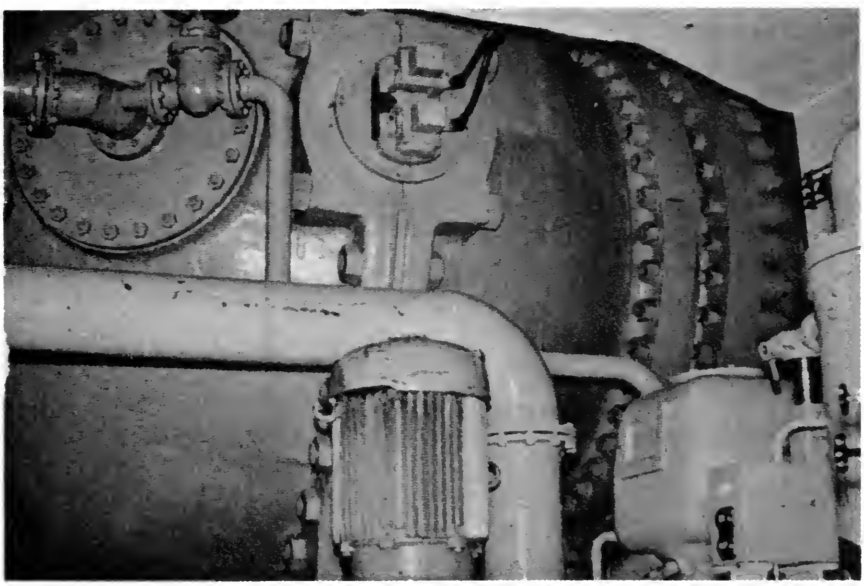


Fig. 3.7 (Gl-19) View of Spherical Valve at Turbine Inlet

## Vibration Records

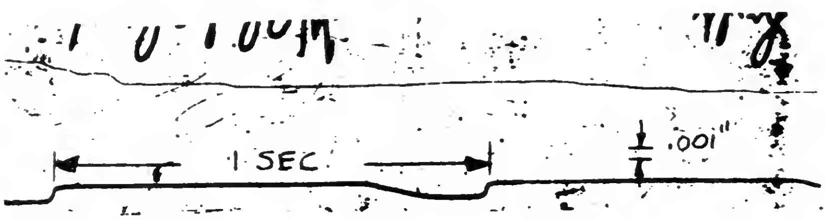
Schluchseewerk AG, Freiburg/Breisgau, Germany

Plant : Waldshut (surface power house)

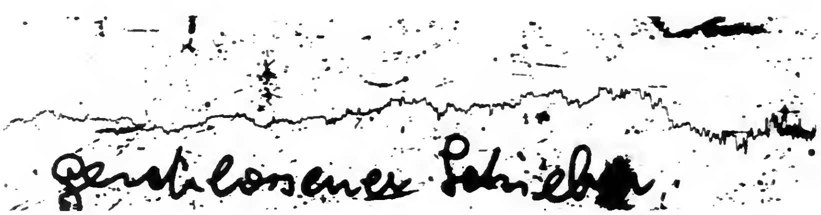
Units : four, 2-stage, single flow, horizontal pumps; 26,800 HP, 353 cfs, 541 ft, 250 RPM

Records-taken : June 25, 1964

Unit A 5 . Horizontal transverse vibration of horizontal, split flange, pump bearing on coupling side. Measured point on split flange.




1. Starting in air



2. Water admitted and air ejected

3. Operation against closed discharge valve

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| ---- | less than .0002 |
| 6600 | .0015 to .0003 |
| 5400 to 6600 | .0003 |

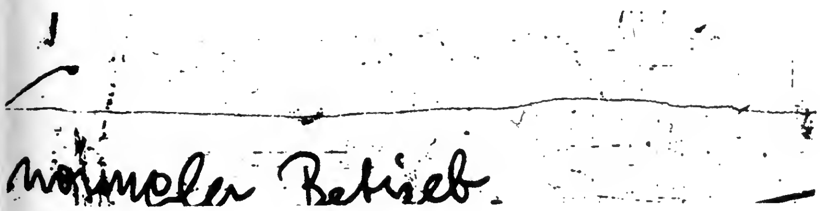
Figure 3-8

## Vibration Records (cont.)

Schluchseewerk AG, Freiburg/Breisgau, Germany

Plant : Waldshut (surface power house)

Unit A 5 : Horizontal transverse vibration of horizontal, split flange, pump bearing on coupling side. Measured point on split flange.




4. Normal pump operation

5. Discharge valve closed

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| ---- | less than .0002 |
| 5400 | .0003 |

Figure 3.9

PLANT NAME: RODUND

REPORT NO.: 4

| | |
|---|---|
| LOCATION-ALTITUDE: | Western Austria - 2110' (near Schruns) |
| OWNER: | Vorarlberger Illwerke A. G. |
| ADDRESS: | Bergenz, Austria |
| TYPE OF PLANT: | Surface |
| SERVICE | Pump Storage - Power Generation |
| TYPE OF WATER: | Good - Clear |
| UNITS INSTALLED: | One 2-stage, double-flow - horizontal. |
| HORSEPOWER: | 53,600 (500 RPM) |
| CFS: | 353 |
| STATIC HEAD: | 1140' |
| PLANT STARTED: | 1952 |
| VISITED BY: | Gartmann-Hartmann-Westman |
| DATE: | July 1, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Mr. T. Läger, Chief of Operations<br>Mr. M. Sandl, Asst. Chief of Operations<br>Mr. Eder, Engineering-Planning |
| REMARKS: | Plant contains four Turbo Generator sets, one of which is connected to storage pump. |

PUMPS:

| | |
|---|---|
| TYPE: | 2-stage - Double-Flow - Horizontal |
| MANUFACTURER: | Voith (Heidenham) |
| SIZE DISCHARGE: | 48" (1200 mm) |
| SIZE SUCTION: | - |
| RPM: | 500 |
| CFS: | 353 |
| HEAD: | 1150' |
| H.P. REQUIRED: | 53,600 |
| N s.: | 1200 |
| INSTALLED: | 1952 |
| HRS. OF OPERATION | 14,225 - as of 3-31-64 (1500 hrs. until 1958 - Approx. 1000 hrs. per year now) |
| MIN. SUBMERGENCE: | 9.85' |
| NORMAL SUBMERGENCE: | 16.4' |
| MAX. SUBMERGENCE: | 26.2' |
| REMARKS: | - |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | - |
| PROTOTYPE-GUARANTEED: | 84% |
| PROTOTYPE-ACTUAL: | 86% |
| METHOD OF TEST: | 25 current meters in discharge. |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 48" (1200 mm) |
| DIAMETER IMPELLER: | 1st - 83.7"; 2nd - 86" |
| DIAMETER EYE: | |
| DIAMETER SHAFT: | - |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | 13% Chrome |
| MATERIAL IMPELLER RINGS: | 13% Chrome |
| MATERIAL-CASING RINGS: | C.I. (one replaced by 13% CR in 1956) |
| RADIAL CLEARANCE: | - |
| MATERIAL BALANCING RINGS: | None |
| MATERIAL INTERSTAGE SEAL: | Babbit Lined |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | Cast Steel |
| BEARING: | Babbitt - 19.7" Dia. |
| THRUST BEARING: | - |

| | |
|---|---|
| TYPE OF PACKING: | Mechanical |
| MATERIAL OF PACKING: | Carbon Rings. (3) in bronze housing. |
| MATERIAL OF SLEEVE: | Chrome plated (.008" -.010") |
| CLEARANCE: | None |
| REMARKS: | Seal water from deep well pumps - always on.<br><br>Pump has movable guide vanes. |

**MOTOR OR GENERATOR:**

| | |
|---|---|
| TYPE: | Horizontal - Synchronous |
| MANUFACTURER: | Siemans - Schuckert |
| H. P.: | 53,600 (40,000 kw) |
| R. P. M.: | 500 |
| VOLTAGE: | 10,400 |
| STARTING: | By Pelton Turbine |
| REMARKS: | Pump dewatered - Guide vanes closed. |

**TURBINE:**

| | |
|---|---|
| TYPE: | Francis |
| MFG.: | Voith |
| HEAD: | - |
| R. P. M.: | 500 |
| H. P.: | 68,000 |
| REMARKS: | Four (4) Turbo sets installed - one connected to pump. |

VALUES:

INTAKE:

| | |
|---|---|
| TYPE: | Stop Locks |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | Crane |

DISCHARGE:

| | |
|---|---|
| TYPE: | Spherical |
| MANUFACTURER: | Escher-Wyss |
| SIZE: | 48" (1200 mm) |
| OPERATION: | - |
| OPENING: | Oil - Hydraulic with Air Pressure Accumulator |
| CLOSING: | |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Surface |
| NO. & SIZE: | One 10' to 10.5' |
| LENGTH: | 28,000' - $29^{o}$ Gradient |

| | |
|---|---|
| MATERIAL: | Steel |
| TYPE OF UPPER GATE: | - |
| SURGE TANK: | None |
| REMARKS: | Upper part rivited - Lower part welded - Set in concrete. |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Good - Clear |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | Solids settle out in Reservoir. |

<u>MAINTENANCE AND OPERATION:</u>

| | |
|---|---|
| OPERATING SCHEDULE: | - |
| STARTS/DAY: | - |
| HOURS OF OPERATION: | - |
| UNPLANNED OUTAGES: | None |
| CAUSE: | - |
| INSPECTION SCHEDULE: | - |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | 1956 - 1964 |
| TIME REQUIRED: | (2) Months - 10 to 15 men. |
| IMPELLER CAVITATION: | No. |

| | |
|---|---|
| SEAL RING WEAR: | No |
| NOISE LEVEL-START: | - |
| NOISE LEVEL-RUN: | - |
| VIBRATION: | None |
| REMARKS: | First stage guide vanes had cavitation and/or corrosion on bottom half only. |

## GENERAL REMARKS

An inspection trip was made by the above personnel to the Rodund plant on July 1, 1964. Discussions were held with the following people:

| | | |
|---|---|---|
| Mr. T. Läuger | - | Chief of Operation |
| Mr. M. Jandl | - | Assistant Chief of Operation |
| Mr. Eder | - | Engineering - Planning |

Rodund is a surface plant containing one horizontal pump-turbine unit and three horizontal Francis turbine units. The pump on the former unit is of Voith manufacture and has a capacity of 10 m3/s against a rated head of 350 m, operating at 500 RPM. The power rating of the pump is 40,000 KW or 53,600 HP.

The pump was installed in 1952 and is now undergoing its second general overhaul. It was, therefore, possible for us to inspect the various pump parts in a dismantled condition.

The pertinent data is given in the summary tabulation. In addition, the following information is presented which was obtained during discussions with the plant engineers and during our inspection: -

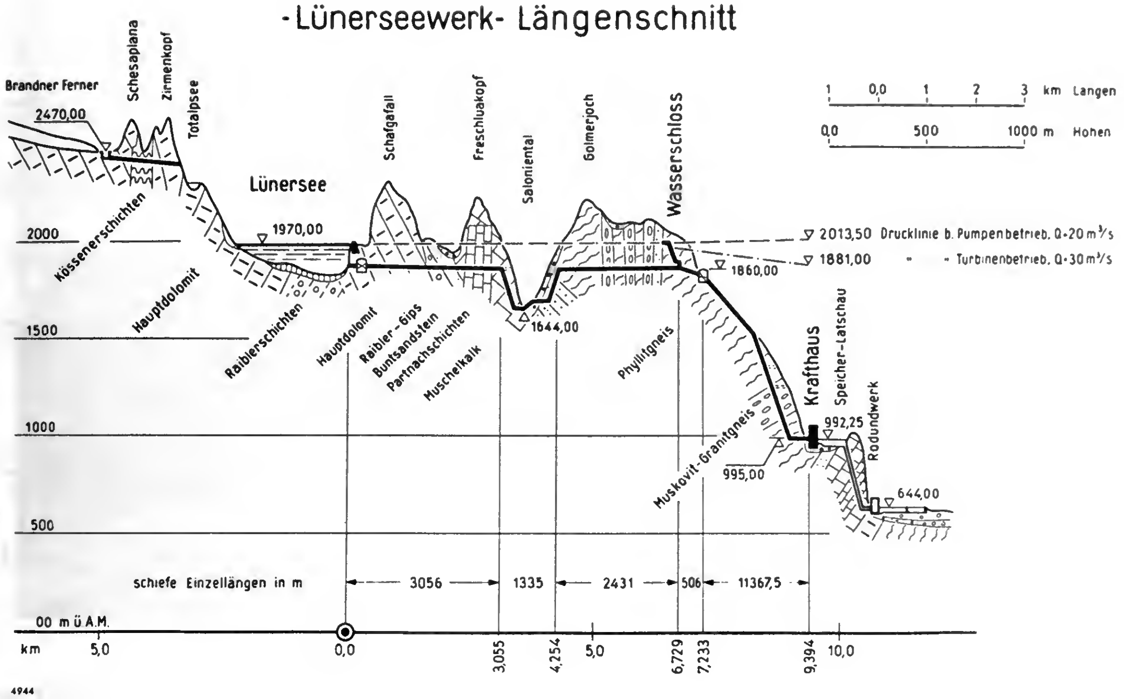
The impellers are made of 13% chrome and are in excellent condition. The impeller wearing rings are also 13% chrome while the matching case rings are made of cast iron. One ring had been rubbing before the 1956 overhaul and was replaced at that time with 13% chrome.

The guide vanes in the pump are cast steel and they show "cavitation", particularly in the bottom half of the pump near the inlet edge, and this was in the process of being repaired by welding. As the damage has only occurred in the lower half, it is doubtful that the cause was cavitation and can probably be blamed on a combination of high velocity and corrosion.

The pump is equipped with three carbon rings at each packing box, which have given excellent service on this installation. As it will be noticed from the summary tabulation, the carbon rings in this instance run against hard chrome plated shaft sleeves.

The units are started dewatered with a Pelton turbine and filtered seal water coming from deep-well pumps is supplied to the various wearing parts.

Fig. 4.1 - View of Rodund Plant



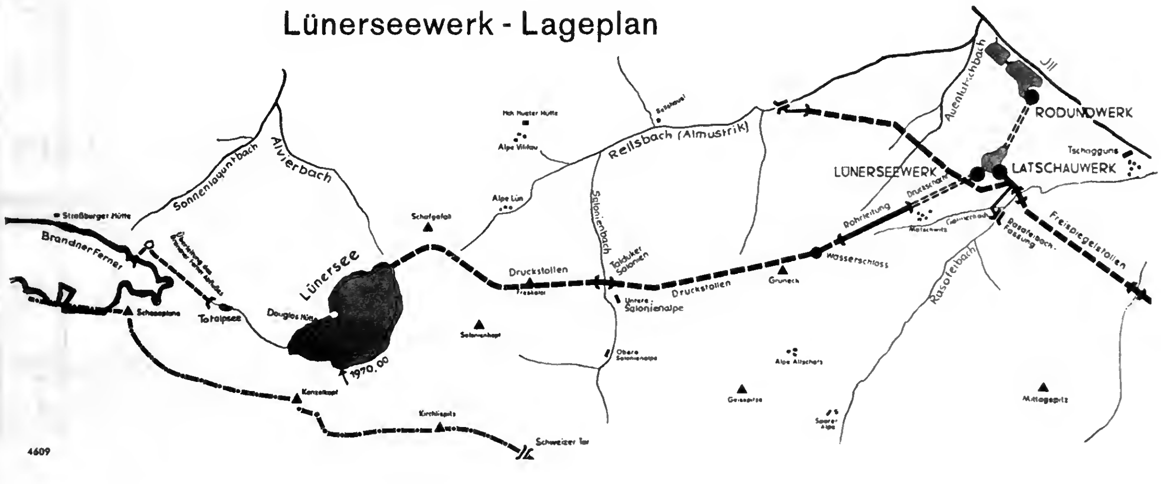




Fig. 4. 2 - Plan and Profile of Lünersee and Rodund System.

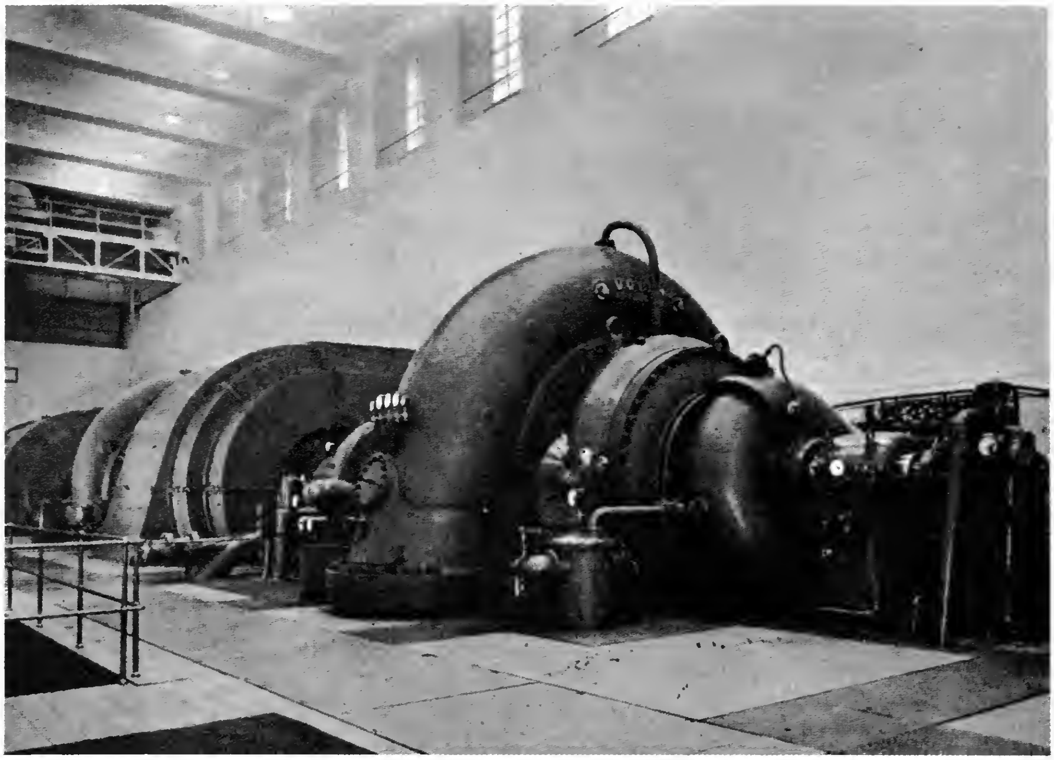


Fig. 4. 3 - Rodund Pump

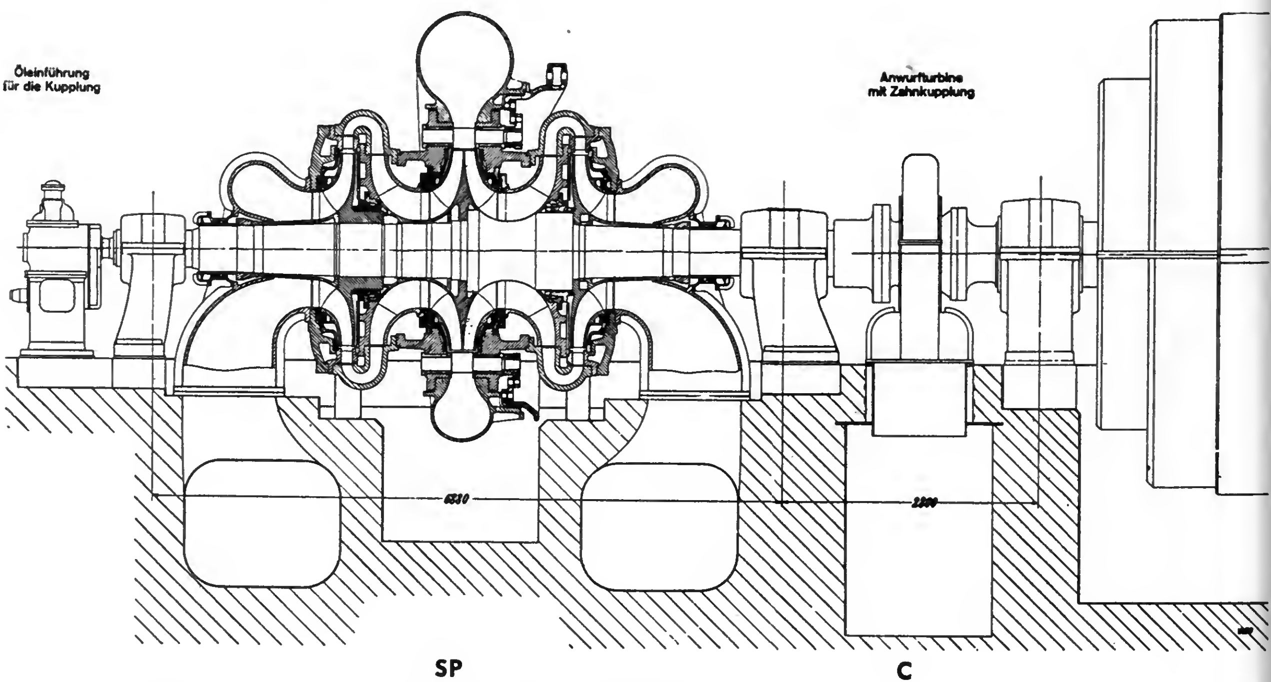



Fig. 4. 4 - Section through Rodund Pump

PLANT NAME: LUNERSEE (LATSCHAU)

REPORT NO.: 5

| | |
|---|---|
| LOCATION-ALTITUDE: | Western Austria - 3250' |
| OWNER: | Vorarlberger Illwerke A. G. |
| ADDRESS: | Bregenz, Austria |
| TYPE OF PLANT: | Surface |
| SERVICE | Pump Storage - Power Generation |
| TYPE OF WATER: | Good |
| UNITS INSTALLED: | Five - 5-stage - Single-flow - Vertical (with Turbine, Torque converter and motor generator) |
| HORSEPOWER: | 55, 500 (750 RPM) |
| CFS: | 154. 8 |
| STATIC HEAD: | 3151' |
| PLANT STARTED: | March 1958 |
| VISITED BY: | Gartmann-Hartmann-Westman |
| DATE: | July 2, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Mr. Hans Neyer, Plant Supt.<br>Mr. R. Boss, Director<br>Mr. Pohl |

REMARKS:

PUMPS:

| | | | | | | |
|---|---|---|---|---|---|---|
| TYPE: | 5-Stage - Single Suction (Horizontal) | | | | | |
| MANUFACTURER: | I & II - Voith; III & IV - Escher Wyss; V - Sulzer | | | | | |
| SIZE DISCHARGE: | Sulzer - 25.6" ; others - 31.5" | | | | | |
| SIZE SUCTION: | - | | | | | |
| RPM: | 750 | | | | | |
| CFS: | 144 | 154.8 | ) | | 132 | ) Sulzer |
| HEAD: | 3150 | 3281 | ) | Actual Conditions | 3186 | ) Guarantee |
| H.P. REQUIRED: | 58,000 | 65,600 | ) | | 54,700 | ) |
| N s.: | 1500 | 1526 | ) | | | |
| INSTALLED: | I- Nov. 1957; III & IV- Dec. 1957; II & V- Jan. 1958 | | | | | |
| HRS. OF OPERATION | 12,000 each (up to 8-1-63)<br>(Approx. 2000 hrs./yr.)<br>Now Approx. 13,500 | | | | | |
| MIN. SUBMERGENCE: | 68.6' | | | | | |
| NORMAL SUBMERGENCE: | 73.8' | | | | | |
| MAX. SUBMERGENCE: | - | | | | | |
| REMARKS: | | | | | | |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | - |
| PROTOTYPE-GUARANTEED: | 88.7 - 89.5 |
| PROTOTYPE-ACTUAL: | - |
| METHOD OF TEST: | - |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | Sulzer - 23.6"; others 31.5" |
| DIAMETER IMPELLER: | 51.3" - 59.2" |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 22" |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | 13% Cr. - 1% Ni |
| MATERIAL IMPELLER RINGS: | 13% Cr. - 300 Brinell |
| MATERIAL-CASING RINGS: | 13% Cr. - 200 Brinell |
| RADIAL CLEARANCE: | 0.5 to 0.75 mm |
| MATERIAL BALANCING RINGS: | 13% Cr. - 1% Ni |
| MATERIAL INTERSTAGE SEAL: | Babbitt & Bronze |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | 13% Cr. Steel |
| BEARING: | 23.6" |
| THRUST BEARING: | Michel |

| | |
|---|---|
| TYPE OF PACKING: | - |
| MATERIAL OF PACKING: | Babbitt - Carbon Rings |
| MATERIAL OF SLEEVE: | Chrome Steel |
| CLEARANCE: | 0.5 mm |
| REMARKS: | Sealing water filtered |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical - Synchronous |
| MANUFACTURER: | Three - Elin; Two - AEG |
| H. P.: | 57,226 |
| R. P. M.: | 750 |
| VOLTAGE: | 10,400 |
| STARTING: | With turbine against closed valve. |
| REMARKS: | Also, start pump with torque converter -- engage gears at 1% slip. |

TURBINE:

| | |
|---|---|
| TYPE: | Pelton |
| MFG.: | Two - Voith |
| HEAD: | 2760' - 3180' |
| R. P. M.: | 750 |
| H. P.: | 62,000 (46,200 KW) |
| REMARKS: | Hydraulic torque converter by Voith between pump and turbine. |

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | Gates |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | - |

DISCHARGE:

| | |
|---|---|
| TYPE: | Needle |
| MANUFACTURER: | Voith - Charmille |
| SIZE: | Sulzer 25.6"; others 31.5" |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | Water Pressure |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | Reverse Speed 200 RPM Max. |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Surface and Underground |
| NO. & SIZE: | One U.G. - 6.73'-7.05'; Surface - 7.38' |
| LENGTH: | UG- 4440' - 6.37' - 7.05'; Surface - 3350' - 7.4'<br>Tunnel - 1640'-10.5' (Surge Tank) - Sphon 4600'<br>7.9' - 8.55' |

| | |
|---|---|
| MATERIAL: | Steel Lined |
| TYPE OF UPPER GATE: | - |
| SURGE TANK: | One - 5500 CF Capacity at entrance of horizontal tunnel. |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Good |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | - |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | May & Aug. (Also daily & weekly) |
| STARTS/DAY: | (500 in 2300 hours) |
| HOURS OF OPERATION: | Approx. 13, 500 |
| UNPLANNED OUTAGES: | - |
| CAUSE: | - |
| INSPECTION SCHEDULE: | Once per year |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | 7 to 9 years |
| TIME REQUIRED: | 6 weeks - 15 men |
| IMPELLER CAVITATION: | yes |

| | |
|---|---|
| SEAL RING WEAR: | - |
| NOISE LEVEL-START: | 110 - 112 |
| NOISE LEVEL-RUN: | A - 91-94; B - 95-98; C - 98-100 |
| VIBRATION: | Negligible |
| REMARKS: | Noise test on Sulzer Pump |

Two impellers repaired by welding, after 8000 hrs. Impellers checked each year.

Balancing leakage increased 20% in 5 years.

Carbon rings replaced each year (2000 hrs.)

Labyrinth packing replaced every 3 - 4 years (9000 Hrs.)

One bearing replaced.

## GENERAL REMARKS

The Vorarlberger Illwerke AG is an enterprise engaged on the construction and operation of power stations harnessing the waters of the River Ill, and its tributaries, and of substations and transmission lines in the Vorarlberg region. The group of power stations on the Upper Ill, comprising those at Obervermunt, Vermunt, Latschau and Rodund, forms a hydrological and economic unity with a common distributing station at Rodund. The total electricity production of these stations, which have an installed output of 400 MVA in all, is distributed to consumers from the transformer station at Bürs near Bludenz.

The Lünersee is a natural Alpine lake situated at an altitude of 6.365 ft. in the Rätikon district near the Swiss frontier. Its useful capacity is at present just over 1,400 million cu. ft., but a dam raises the top water level to 6,463 ft. and, thereby, increases the capacity of the lake to about 2,685 million cu. ft. The waters stored here generate electricity in two sections; an upper one at Latschau utilizing a head of 3,280 ft., and a lower one at Rodund with a head of 1,150 ft.

The natural run-off from the Lünersee catchment area is only about 600 million cu. ft. per year. The additional 2,085 million cu. ft. needed to fill the lake is pumped up from the Latschau basin, 203 million kWh of summer night current being used for the purpose.

The water thus stored enables 152 million kWh to be produced each year in the main station at Latschau, and a further 57 million kWh in the station at Rodund, making in all 209 million kWh of peak power for winter use. The Lünersee station, however, is not used only for seasonal storage but also for daily and week-end operation. In this way an additional 200 million kWh can be converted into peak current each year, which brings the total annual power generation of the Lünersee scheme up to about 400 million kWh.

The Lünersee station stands beside the Latschau Reservoir at an altitude of about 3,280 ft. and is equipped with five vertical sets each comprising motor-generator, turbine and pump. The power supply company ordered from Sulzer Brothers a five-stage high-lift storage pump for the following mean working data; discharge 49,250 gals. per min., total head 3,186 ft., speed 750 RPM, input 54,750 H.P. The maximum power required is nearly 70,000 H.P.

The Lünersee pumps are designed for a maximum working pressure of 2,700 lb. per sq. in.

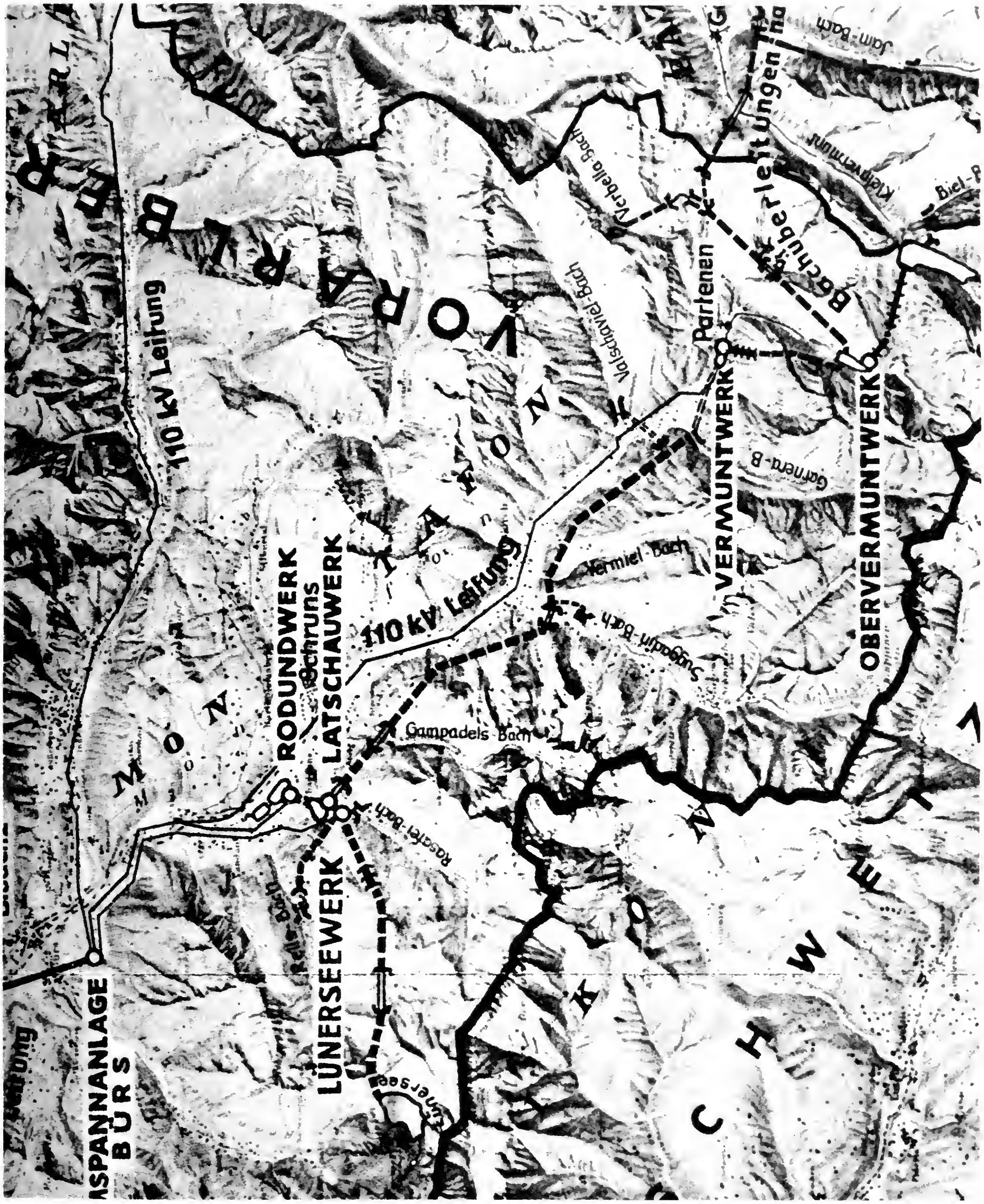



Fig. 5. 1 - Map of Vorarlberger System


Fig. 5.2 - View of Lünersee Plant (B) and Rodund (D).
(C) indicates location of the surge tank.

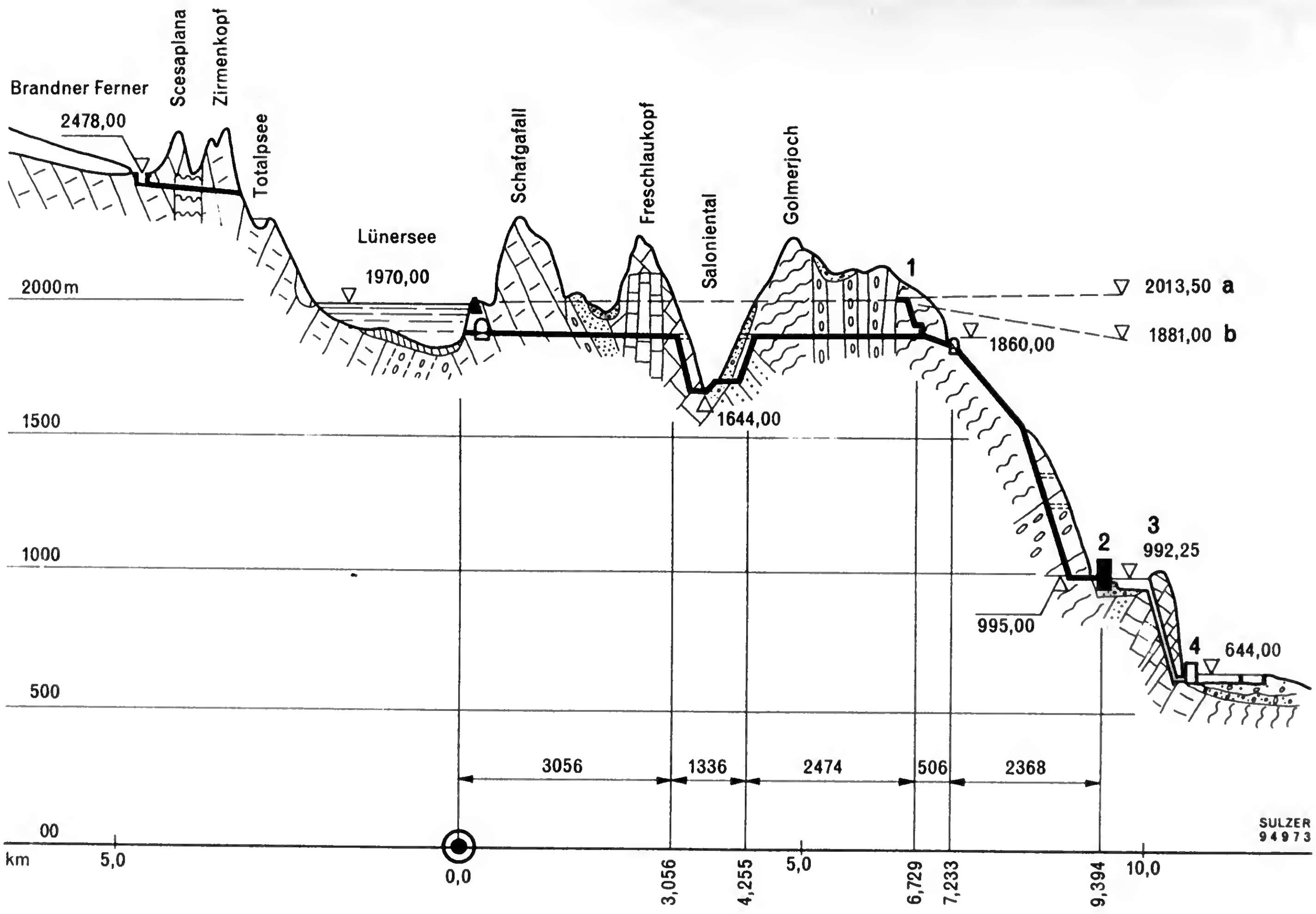



Fig. 5. 3 - Profile of Lünersee and Rodund System

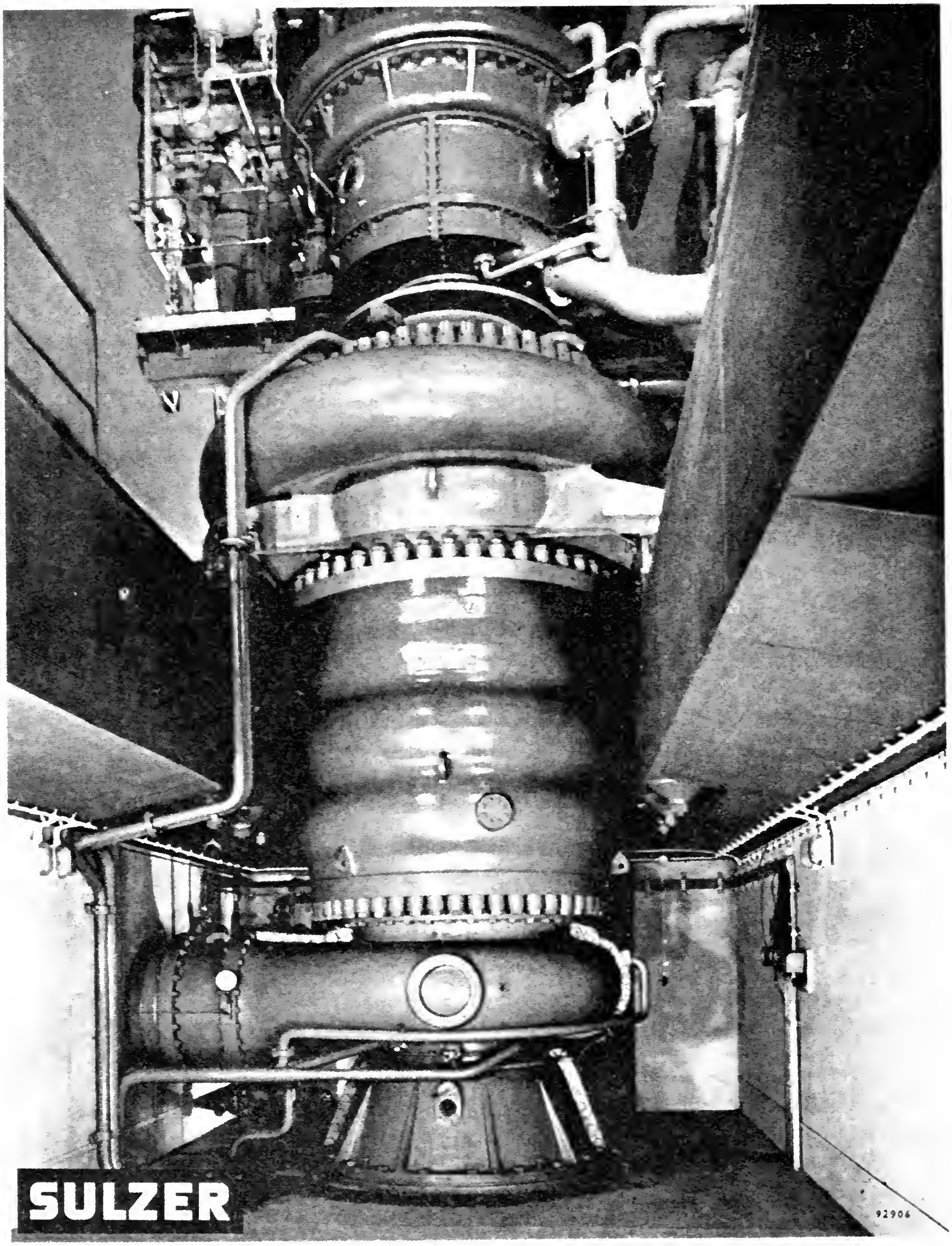



Fig. 5.4 - View of Lünersee Pump

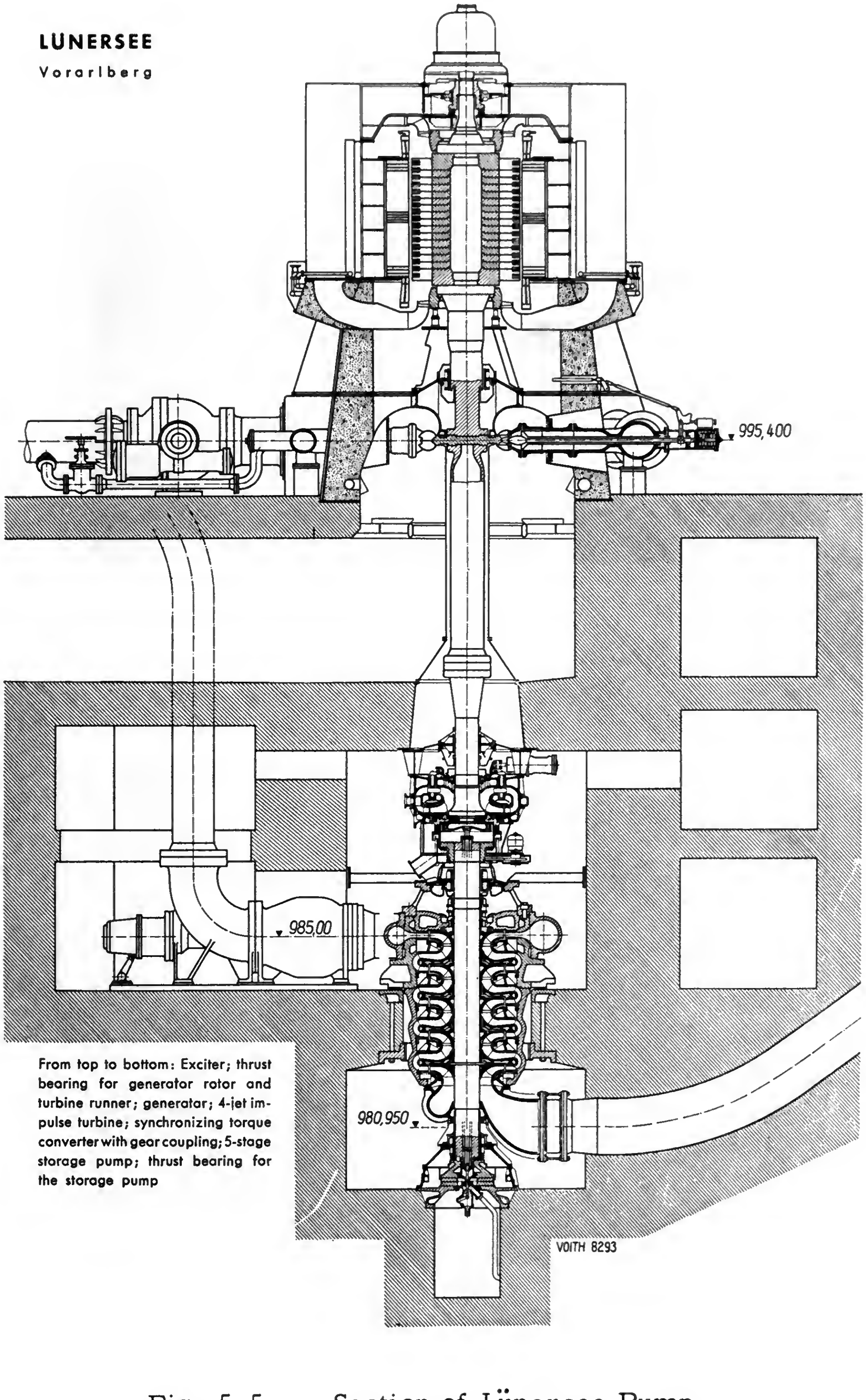



Fig. 5.5 - Section of Lünersee Pump.

Fig. 5.6 (G2-20) Forebay

Fig. 5.7 (G2-17) Valve Chamber

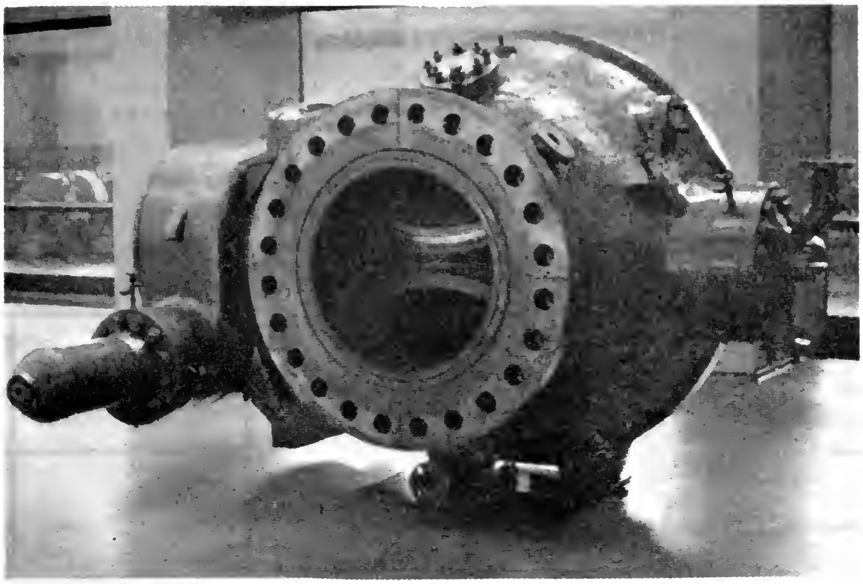


Fig. 5.8 (G2-18) Spherical Valve

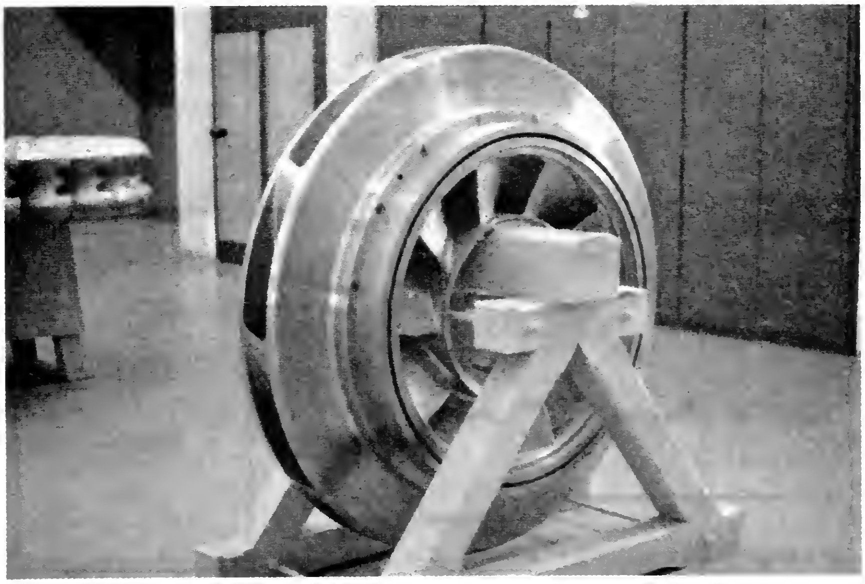


Fig. 5.9 (G2-19) Impeller

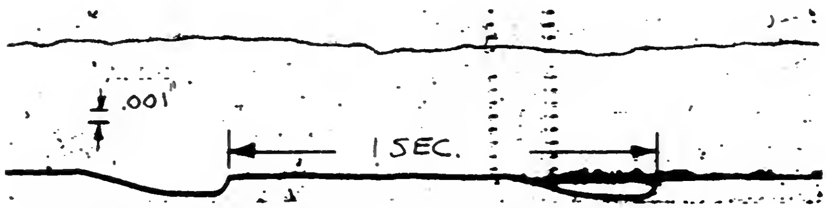
## Vibration Records

Vorarlberger Illwerke AG, Bregenz, Austria

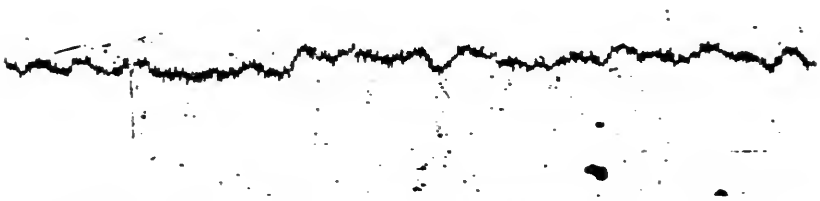
Plant : Lünersee (surface power house)

Units : five, 5-stage, single flow, vertical pumps; 57,200 HP, 155 cfs, 3281 ft, 750 RPM

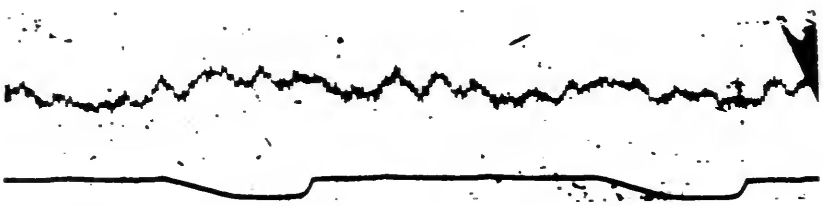
Records taken : July 2, 1964




1. Unit 5, Volute casing - normal operation



2. Unit 5, Volute casing - discharge valve closed



3. Unit 5, Volute casing - discharge valve closed, torque converter in operation

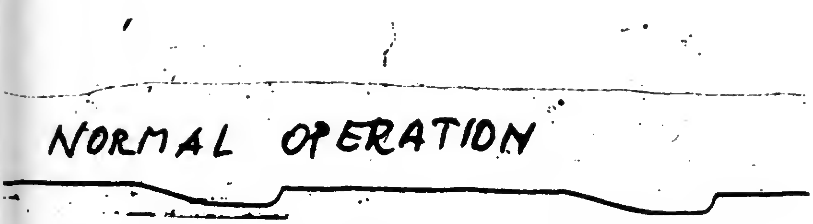
| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 7680 | .0002 |
| 7680 | .0009 |
| 7680 | .0008 |

Figure 5-10

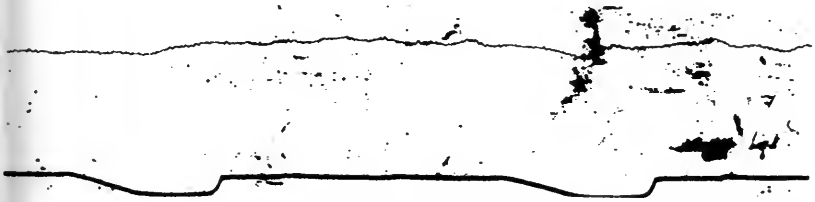
## Vibration Records (cont.)

Vorarlberger Illwerke AG, Bregenz, Austria

Plant : Lünersee (surface power house)




4. Unit 4, Volute casing - normal operation



5. Unit 4, Volute casing - discharge valve closed

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| ---- | less than .0002 |
| ---- | .0002 |

Figure 5-11

PLANT NAME: FERRERA

REPORT NO.: 7

| | |
|---|---|
| LOCATION-ALTITUDE: | Near Innerferrera, Switzerland - 4600' |
| OWNER: | Kraftwerke, Hinterrhein, AG. |
| ADDRESS: | Thusis, Switzerland |
| TYPE OF PLANT: | Underground |
| SERVICE | Pump Storage - Generating |
| TYPE OF WATER: | Very good - Lake Water |
| UNITS INSTALLED: | Two - 2-stage, horizontal, single-suction (overhung)<br>Turbines and Generator - same shaft |
| HORSEPOWER: | 27,833 (750 RPM) |
| CFS: | 141 |
| STATIC HEAD: | 1600' maximum - 1255' minimum |
| PLANT STARTED: | 1962 |
| VISITED BY: | Gartmann - Hartmann - Westman |
| DATE: | July 7, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Mr. B. Schupp |

REMARKS: Owned 20% by Societa Edison; Miland, 19.5% by City of Zurich; 19.5% by NOK; rest by other Swiss entities.

Operate during the Summer to lift snow melt to Valle Di Lei Reservoir (197 million $M^3$) at 6340' to 6000'.

PUMPS:

| | | | |
|---|---|---|---|
| TYPE: | Two-stage - Horizontal -Single-Suction | | |
| MANUFACTURER: | Escher Wyss | | |
| SIZE DISCHARGE: | 29.5" (750 mm) | | |
| SIZE SUCTION: | - | | |
| RPM: | 750 | | |
| CFS: | 173 | 141 | |
| HEAD: | 1305 | 1530 | |
| H.P. REQUIRED: | 30,200 | 27,833 | |
| N s.: | 1630 | 1295 | |
| INSTALLED: | 1962 | | |
| HRS. OF OPERATION | I | II | III |
| Pump | 2777 | 1866 | (not installed) |
| Turbine | 4250 | 3660 | 4273 |
| MIN. SUBMERGENCE: | - | | |
| NORMAL SUBMERGENCE: | 1182 | | |
| MAX. SUBMERGENCE: | - | | |
| REMARKS: | Booster pumps have capacity of 141 CFS against 137.5'. | | |

| | |
|---|---|
| TYPE OF PACKING: | - |
| MATERIAL OF PACKING: | - |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | - |
| MANUFACTURER: | Oerlikon |
| H. P.: | 27, 900 (20, 800 kw)<br>(70, 000 kva as generator) |
| R. P. M.: | 750 |
| VOLTAGE: | 10, 500 |
| STARTING: | By Turbine against closed valve |
| REMARKS: | - |

TURBINE:

| | |
|---|---|
| TYPE: | Horizontal - Francis |
| MFG.: | Escher Wyss - Charmilles |
| HEAD: | 1552' |
| R. P. M.: | 750 |
| H. P.: | 83, 500 (62, 300 kw) |
| REMARKS: | - |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | No information |
| MODEL ACTUAL: | - |
| PROTOTYPE-GUARANTEED: | - |
| PROTOTYPE-ACTUAL: | - |
| METHOD OF TEST: | - |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 29.5" (750 mm) |
| DIAMETER IMPELLER: | - |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | - |
| MATERIAL CASING: | - |
| MATERIAL IMPELLER: | - |
| MATERIAL IMPELLER RINGS: | - |
| MATERIAL-CASING RINGS: | - |
| RADIAL CLEARANCE: | - |
| MATERIAL BALANCING RINGS: | - |
| MATERIAL INTERSTAGE SEAL: | - |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | - |
| BEARING: | - |
| THRUST BEARING: | - |

VALUES:

INTAKE:

| | |
|---|---|
| TYPE: | Butterfly |
| MANUFACTURER: | Von Roll |
| SIZE: | - |
| OPERATION: | Oil to open, counter-weight to close, self-opening on return flow |

DISCHARGE:

| | |
|---|---|
| TYPE: | Needle (two plungers) |
| MANUFACTURER: | Von Roll |
| SIZE: | 29.5" (750 mm) |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | Water Pressure |
| TIME OF CLOSING: | - |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | - |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | One - 9.85' to 10.8' |
| LENGTH: | 1665' (into 14.1' tunnel, 22,600' long) |

| | |
|---|---|
| MATERIAL: | - |
| TYPE OF UPPER GATE: | - |
| SURGE TANK: | At pump end of tunnel |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Very good |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | Potable after simple filtration |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | Summer only |
| STARTS/DAY: | - |

HOURS OF OPERATION:

| | I | II | III |
|---|---|---|---|
| Pump. | 2777 | 1866 | (not inst.) |
| Turbine | 4250 | 3670 | 4273 |

| | |
|---|---|
| UNPLANNED OUTAGES: | One |
| CAUSE: | Stuffing box got hot |
| INSPECTION SCHEDULE: | Once per year |
| TIME REQUIRED: | One week - one shift (4 men) |
| OVERHAUL SCHEDULE: | Three years |
| TIME REQUIRED: | No schedule |
| IMPELLER CAVITATION: | None |

| | |
|---|---|
| SEAL RING WEAR: | - |
| NOISE LEVEL-START: | 98 DB |
| NOISE LEVEL-RUN: | 95 DB |
| VIBRATION: | None (.0002" running) |
| REMARKS: | .003" Vibration on elbow during starting. |

## GENERAL REMARKS

The main units in Ferrera station are three horizontal-shaft 62.3 MW 750 RPM assemblies, each comprising a Francis turbine, an alternator-motor, and main and pilot exciters. Two of the main units are at present equipped with a storage pump, coupled by a removable tooth-type clutch.

The castings for the turbine spiral casings, covers, runners, and alternator-rotor spiders were supplied by George Fischer Limited, Schaffhausen, who also provided a spare runner and a spare turbine cover.

The turbines were built by a consortium of Escher Wyss and Charmilles, both firms sharing in the design and in the necessary laboratory work. These machines are remarkable because they represent one of the highest-head Francis installations in the world, the gross head being 525 m and the net head 474 m at full load of all three units. Each turbine develops 98,100 HP at rated full load, with a discharge of 15 $m^3$/sec.

The alternator-motors were supplied by Oerlikon Engineering Co., Ltd., and as alternators are rated at 70 MVA and generate at 10.5 kV.

The two-stage, single-flow main storage pumps are of Escher Wyss manufacture; each absorbs 30.620 HP when raising a 4.9 $m^3$/ sec against a gross head of 397.5 m.

The main transformers are housed in cubicles built against the side wall of the machine hall, and are placed opposite to their respective generating sets. Each set is served by a bank of three single-phase transformers, the bank being rated at 70 MVA and stepping up to 225 kV. A tenth single-phase unit is available as a reserve, all units having been supplied by Sécheron.

The main generators are paralleled and switched on the high-voltage side of the transformer banks by circuit breakers in the outdoor switchyard, but they can also be connected to an auxiliary 10.5 kV bus-bar. The latter also feeds the station services.

Connection between the transformer banks and the switchyard is effected by ten 225 kV oil-fitted cables, one of them serving as reserve.

The switchyard is laid out for the eventual adoption of a double-busbar system. Each generator is controlled by an 11,500-MVA Brown Boveri circuit breaker.

The two auxiliary pump-turbine units are vertical machines, consisting of Sulzer pump-turbine units coupled to Brown Boveri asynchronous motors/alternators and running at 600 r.p.m. The pump-turbines absorb 2496 h.p. as pumps, with a discharge of 4 $m^3$/sec under a head of 41.9 m and deliver 2000 h.p. as turbines with a flow of 4.2 $m^3$/sec under a head of 44 m. The electrical machines are rated at 1800 kVA as alternators and 2200 kW as motors. They are connected to the 10.5-kV auxiliary bus bar through a 10-5/3.3-kV, 5200-kVA Brown Boveri transformer.

During the snowmelt the flow from the Innerferrera intake is lifted by the main storage pumps to Valle di Lei reservoir. It may also be desired to transfer surplus water from Sufers reservoir, in which event these two auxiliary machines operate as booster pumps to lift the water to the main-pump suction conduit. In winter the flow from the Averserrhein is passed to Sufers reservoir, and these machines then act as turbines to take advantage of the available head at Innerferrera.

A medium-voltage service connection with Bärenburg and power supplies to the pressure-shaft head valve and to the Innerferrera dam are furnished at 16 kV by a 4000-kVA Sécheron regulating transformer fed from the 10.5-kV auxiliary busbar. When no power is available either from the main generators or from the pump-turbine sets power can be supplied to the valve chamber, the intake, the station services and the village of Innerferrera direct from Bärenburg; Bärenburg power can also be fed back through the 225-kV transformers to drive the pump-turbines as booster pumps.

The station supply at 380 V is derived from the 16-kV system through a 1000-kVA Sécheron regulating transformer. For emergency use a 550-kVA diesel generating set supplied by Swiss Locomotive and Machine Works. Winterthur is housed in an exterior building and is connected to the 380-V busbars. It can also be used to operate the pressure-shaft head valve through a300-kVA transformer stepping up to 16 kV.

The main control room is located at one end of the machine hall, and has been equipped by Electro Tableau, Bienne.

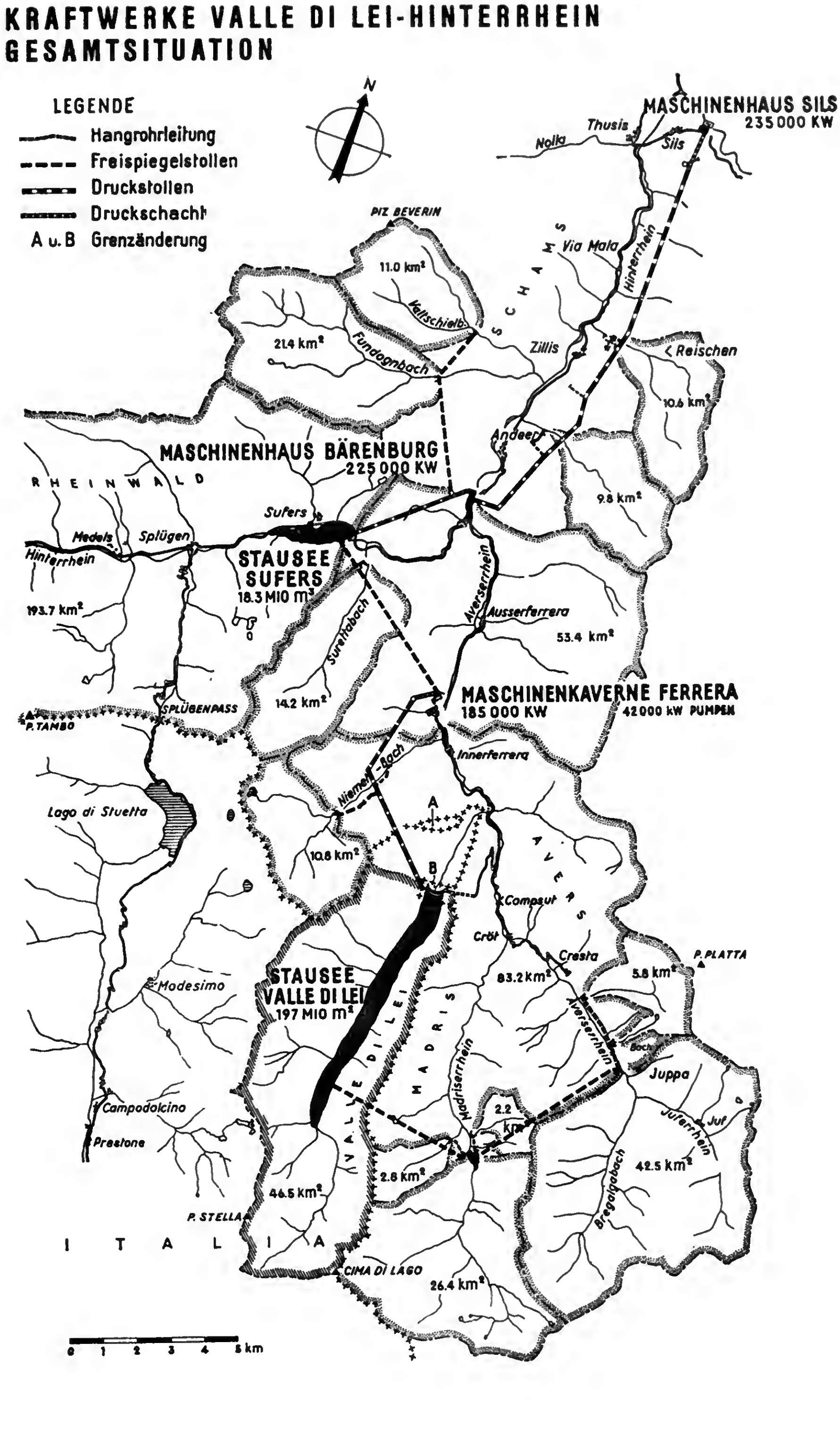



Fig. 7. 1 - General Plan of System

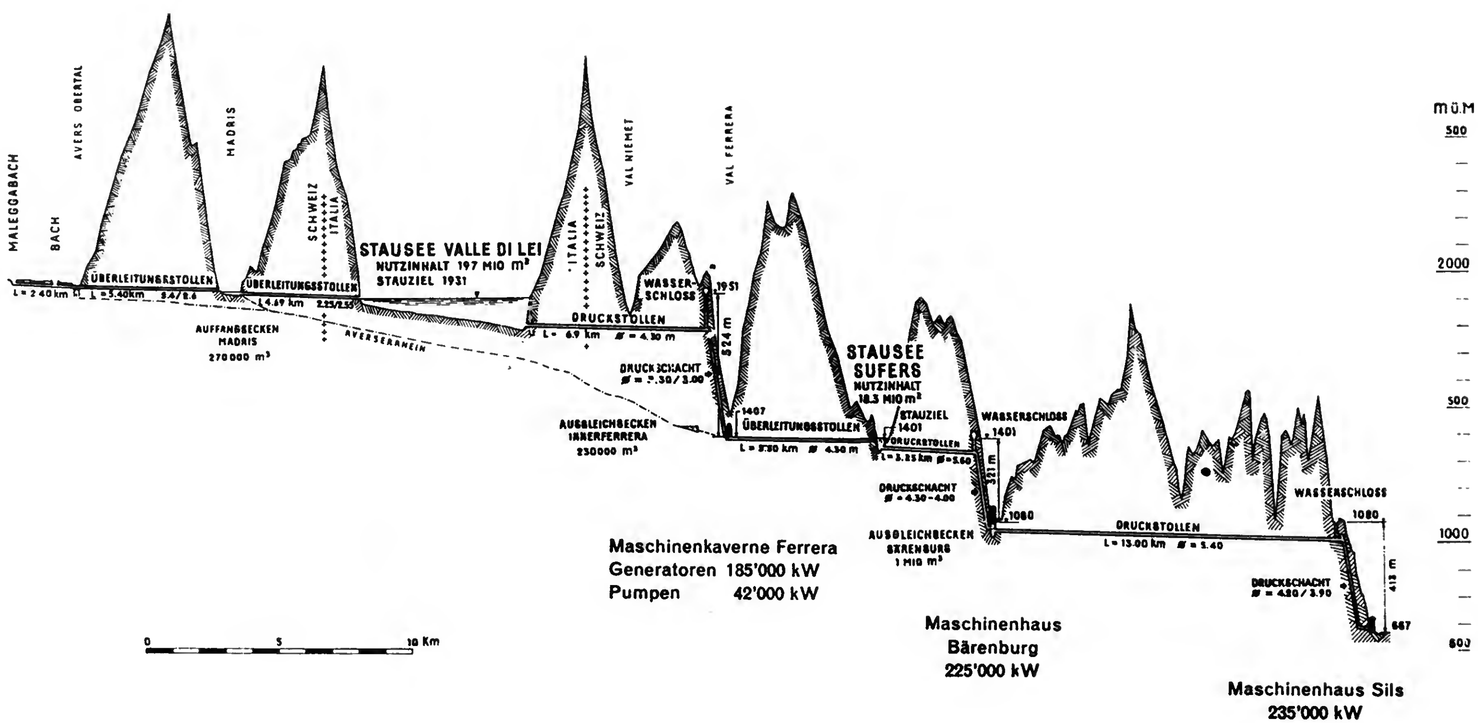



Fig. 7.2 - Profile of System

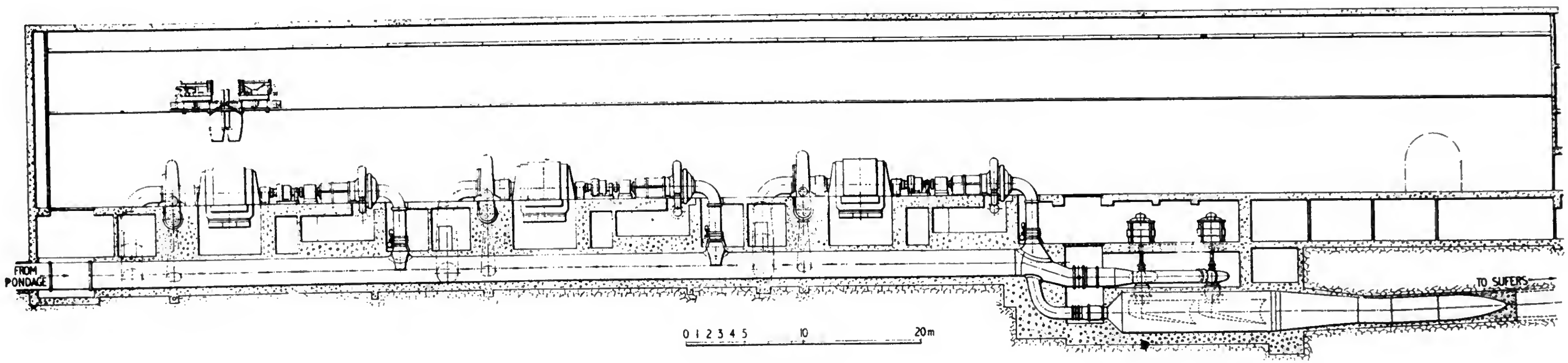



Fig. 7.3 - Longitudinal Section through Station.
(only two pumps installed at present)

## LAGEPLAN DES KRAFTWERKES FERRERA

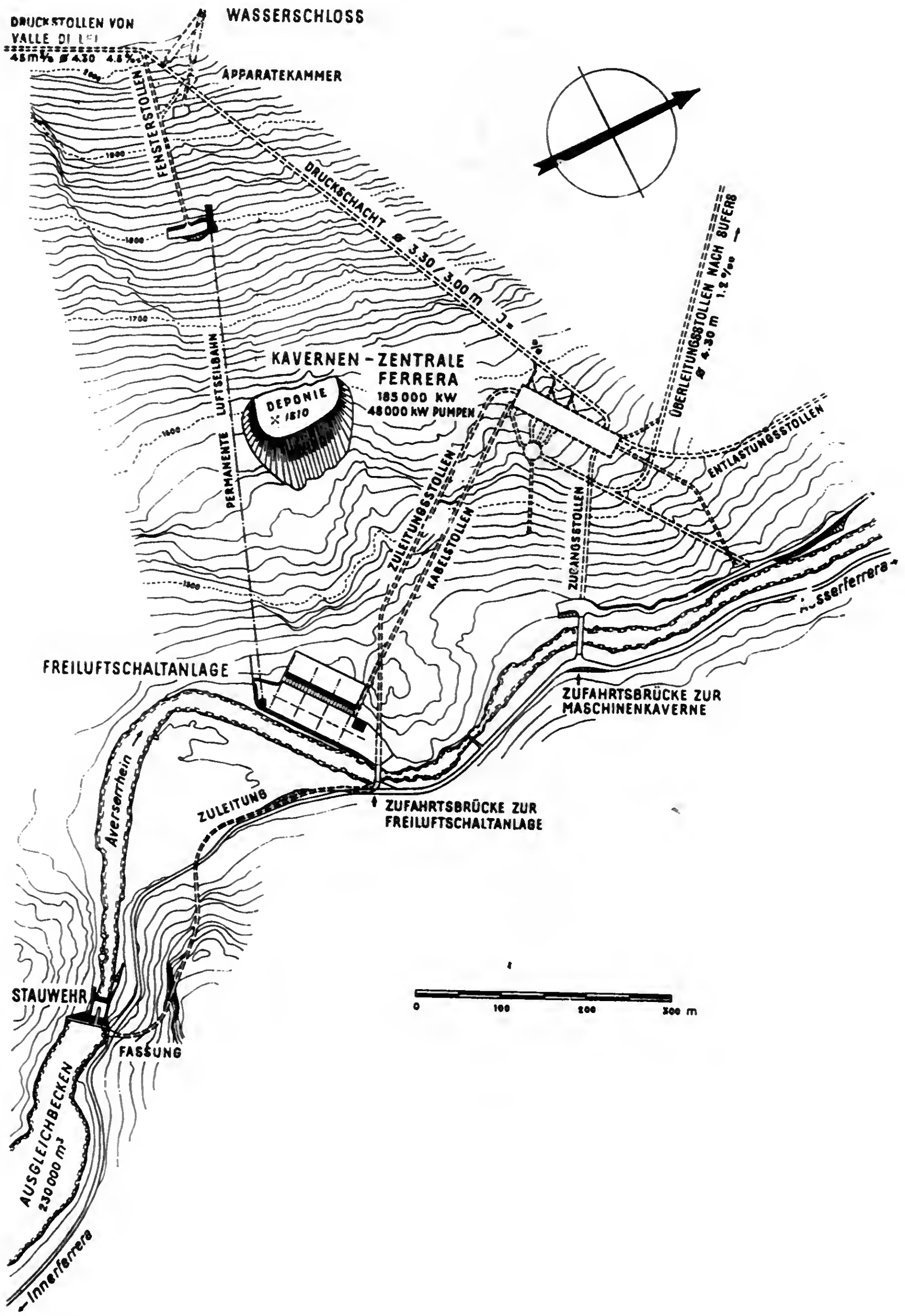



Fig. 7.4 - Plan of Plant and Penstocks

Fig. 7.5 (G3-2) Plant Entrance

Fig. 7.6 (W2-4) Plant Interior


Fig. 7.7 (G3-13) Drive end of Pump

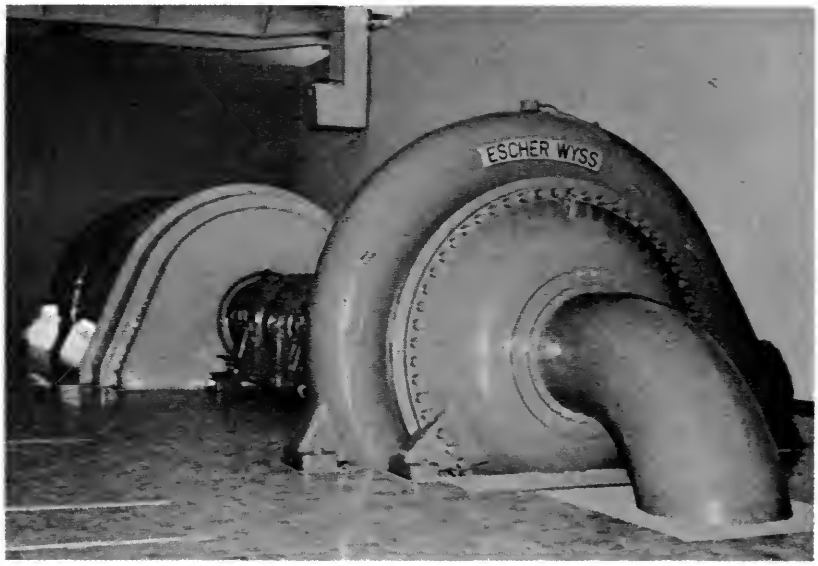



Fig. 7.8 (G3-11) Suction end of Pump

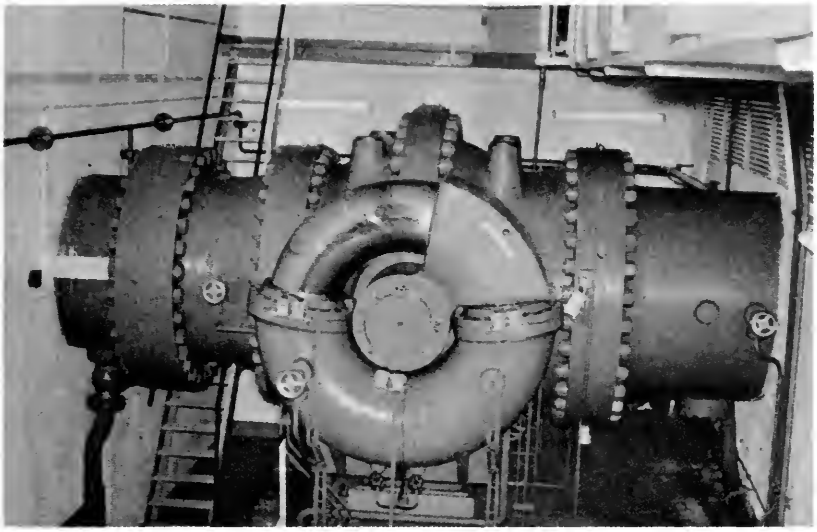


Fig. 7. 9 (G3-14) Von Roll Intake Valve

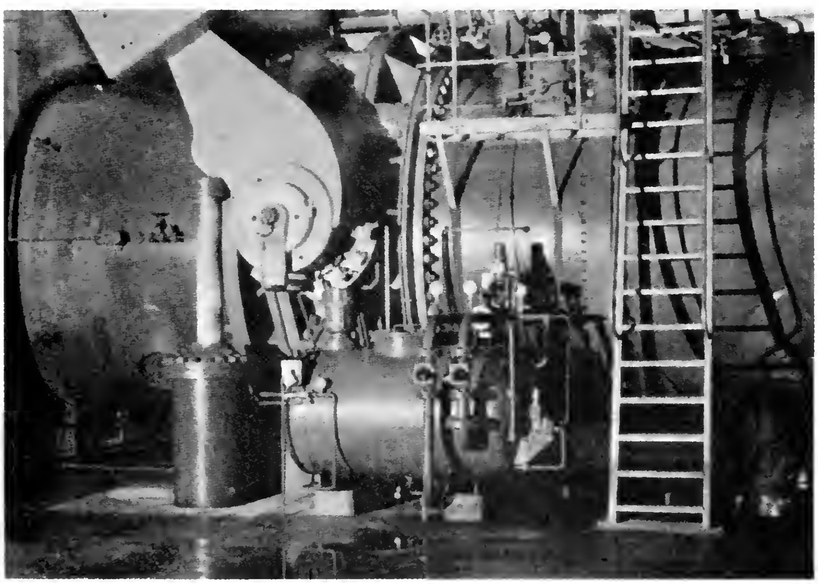


Fig. 7-10 (G3-7) Von Roll Intake Valve

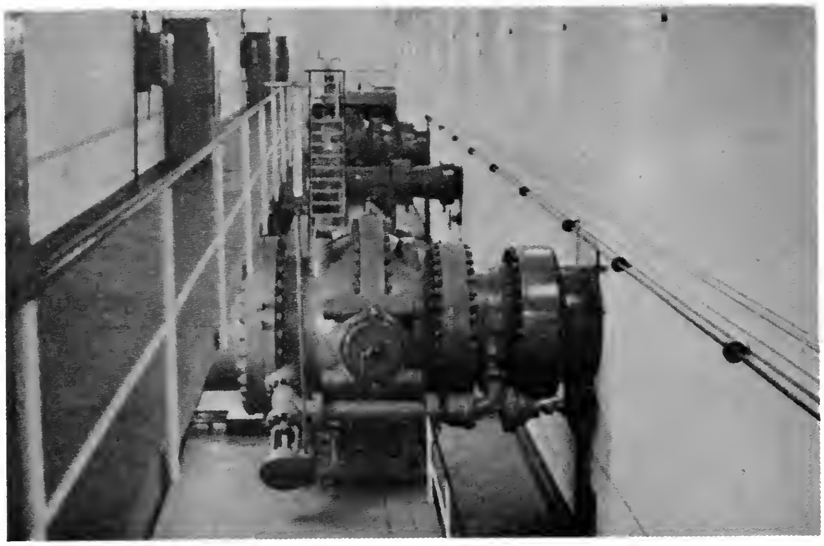


Fig. 7.11 (G3-4) Valve Chamber

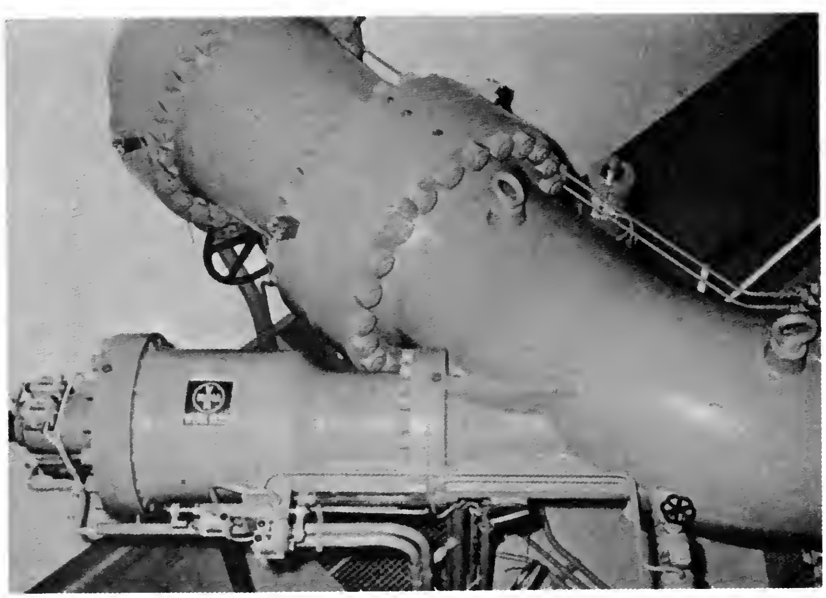


Fig. 7.12 (W2-00) Needle Discharge Valve

## Vibration Records

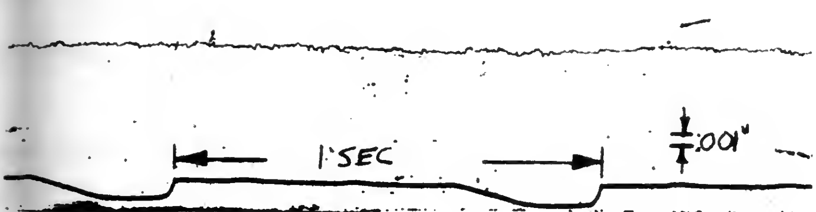
Kraftwerke Hinterrhein AG, Thusis, Switzerland

Plant : Ferrera (underground power house)

Units : two, 2-stage, single flow, horizontal pumps; 27,800 HP, 141 cfs, 1529 ft, 750 RPM

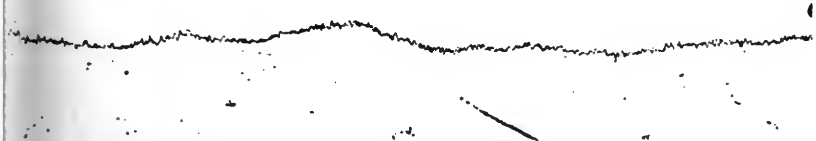
Records-taken : July 7, 1964

Unit 1




1. Shaft near coupling - discharge valve closed

hut off volute casing



2. Volute casing - discharge valve closed

volute

3. Volute - discharge valve closed

discharg

4. Discharge pipe at volute - discharge valve closed

| Record | Frequency c.p.m. | Average Amplitude inches |
|---|---|---|
| 1 | ---- | .0003 |
| 2 | ---- | .0005 |
| 3 | 12,000 | .0003 |
| 4 | 9000 | .0005 |

Figure 7.13

## Vibration Records (cont.)

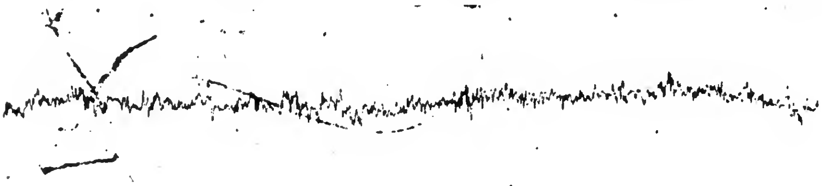
Kraftwerke Hinterrhein AG, Thusis, Switzerland

Plant : Ferrera (underground power house)

Unit 1 (cont.)

ute casing before flange,

5. Volute casing, before flange - discharge valve closed

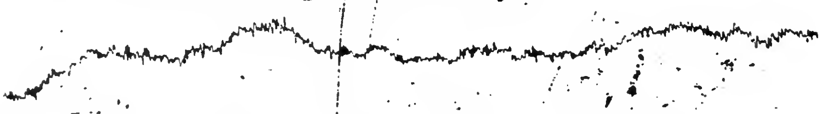


6. Volute, other side - discharge valve closed

elbow

7. Suction elbow - discharge valve closed

return casing



8. Return casing - discharge valve closed

shaft

9. Shaft - discharge valve closed

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 13,300 | .0013 |
| 12,000 | .0013 |
| 13,300<br>660 | .0013<br>.0035 |
| 12,750 | .0010 |
| ---- | .0002 |

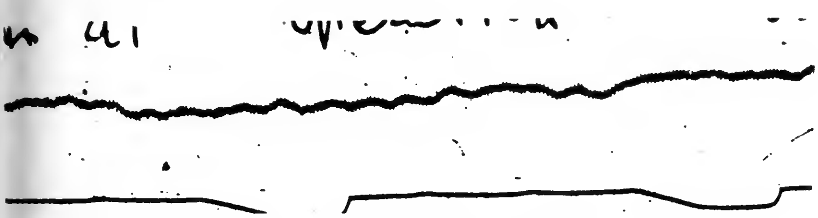
Figure 7.14

## Vibration Records (cont.)

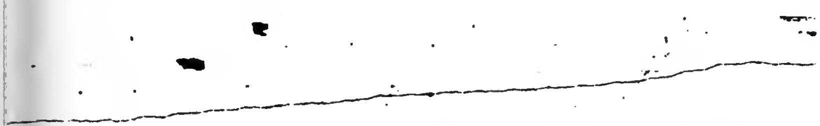
Kraftwerke Hinterrhein AG, Thusis, Switzerland

Plant : Ferrera (underground power house)

Unit 1 (cont.)

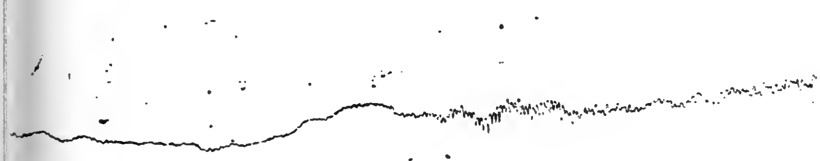


10. Volute (same point as record 5) - normal operation

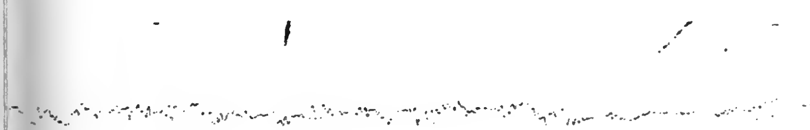


ft normal operation

11. Shaft - normal operation



12. Needle valve - while closing



13. Needle valve - closed

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 14, 250 | .0008 |
| ---- | less than .0002 |
| 14,000 to 7200 to 6000 | less than .0002 to .0010 |
| 4800 | .0010 |

Figure 7.15

PLANT NAME: PECCIA

REPORT NO.: 9

| | |
|---|---|
| LOCATION-ALTITUDE: | PECCIA (South Switzerland) 3400' |
| OWNER: | Maggia Kraftwerke A. G. |
| ADDRESS: | Locarno, Switzerland |
| TYPE OF PLANT: | Underground |
| SERVICE | Utility Power<br>Pump Storage |
| TYPE OF WATER: | Very good |
| UNITS INSTALLED: | Two 2-stage single flow - Horizontal pumps only. |
| HORSEPOWER: | 13,600 |
| CFS: | 83.6 |
| STATIC HEAD: | 1390' (Max.) |
| PLANT STARTED: | End of 1955 |
| VISITED BY: | Gartmann-Hartmann-Westman |
| DATE: | July 8, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Messrs.<br>F. Stoffel, Director<br>A. Pagani, Director<br>G. Stanza, Engineer<br>E. Luminati, Plant Supt. |

REMARKS: Pumps take water from Peccia compensating reservoir at 3720' - 3390' and return it to Sambuco Reservoir at 4500'.

Plant also contains two Pelton type Turbo-Generator sets.

## PUMPS:

| | |
|---|---|
| TYPE: | Horizontal - 2-stage single suction |
| MANUFACTURER: | Sulzer |
| SIZE DISCHARGE: | 23.6" (600 mm) |
| SIZE SUCTION: | 27.5" (700 mm) |
| RPM: | 1000 |
| CFS: | 83.7 |
| HEAD: | 1230 |
| H.P. REQUIRED: | 13,400 |
| N s.: | 1568 |
| INSTALLED: | End of 1955 |
| HRS. OF OPERATION | I - 6640 II - 6580 |
| | (Approx. 1000 hrs. /year) |
| MIN. SUBMERGENCE: | 59' |
| NORMAL SUBMERGENCE: | - |
| MAX. SUBMERGENCE: | 69' |

REMARKS: Pumps supplied from a collector about 60' above the pumps which is filled partly from in-flow, and partly by two mixed flow pumps which pick up water from the tail race of the turbines.

| | |
|---|---|
| TYPE OF PACKING: | Labyrinth |
| MATERIAL OF PACKING: | Babbitt |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | 0. 2 mm |
| REMARKS: | Balancing Labyrinth leaked 318 GPM when new, 460 GPM after 6000 hrs. (Replace when leakage reaches 555 GPM |

**MOTOR OR GENERATOR:**

| | |
|---|---|
| TYPE: | Horizontal Synchronous 95% P. F. |
| MANUFACTURER: | Oerlikon (Zurich) |
| H. P.: | 16. 200 H. P. (12000 kw) |
| R. P. M.: | 1000 |
| VOLTAGE: | 12, 000 |
| STARTING: | Reduced voltage - closed valve |
| REMARKS: | Reverse speed at full head reaches 1250 RPM -125%). |

**TURBINE:**

| | |
|---|---|
| TYPE: | None with pump |
| MFG.: | - |
| HEAD: | - |
| R. P. M.: | - |
| H. P.: | - |
| REMARKS: | - |

## EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | No model made |
| MODEL ACTUAL: | " " " |
| PROTOTYPE-GUARANTEED: | 1080' - 82%; 1230' - 86% |
| PROTOTYPE-ACTUAL: | Exceeded guarantee by 1.1% |
| METHOD OF TEST: | *Flow meters in suction |

## CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 23.6" |
| DIAMETER IMPELLER: | (45") 48.8" (9 vanes) |
| DIAMETER EYE: | 27.2" |
| DIAMETER SHAFT: | 11" - 11.8" |
| MATERIAL CASING: | Cast Iron |
| MATERIAL IMPELLER: | 13% Cr. Steel |
| MATERIAL IMPELLER RINGS: | Bronze |
| MATERIAL-CASING RINGS: | Cast Iron |
| RADIAL CLEARANCE: | 0.44 - 0.58 mm |
| MATERIAL BALANCING RINGS: | (10 Labyrinths) |
| MATERIAL INTERSTAGE SEAL: | - |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | - |
| BEARING: | 10" (Oil cooled) |
| THRUST BEARING: | Kingsbury type - double active on motor and pump. |

*Have Venturi meters in suction but used for station operation only.

VALVES:

| | |
|---|---|
| INTAKE: | None - Check valve on booster discharge. |
| TYPE: | - |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | - |

DISCHARGE:

| | |
|---|---|
| TYPE: | Needle and Spherical |
| MANUFACTURER: | Von Roll |
| SIZE: | 23.6" (600 mm) |
| OPERATION: | |
| OPENING: | Needle - Oil and Water<br>Spherical - Water pressure |
| CLOSING: | Ditto |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | Time of closing adjusted to alleviate surges. |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | One - 4' to 13.1' |
| LENGTH: | No Data - (Almost vertically - Horizontal Tunnel 20,000' ± ) |

| | |
|---|---|
| MATERIAL: | - |
| TYPE OF UPPER GATE: | Von Roll Gates |
| SURGE TANK: | At pump end of tunnel |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Very good |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | Upper Reservoir has a capacity of 63. 3 million $M^3$ (51, 200 AF) |

<u>MAINTENANCE AND OPERATION:</u>

| | |
|---|---|
| OPERATING SCHEDULE: | - |
| STARTS/DAY: | - |
| HOURS OF OPERATION: | I - 6640; II- 6580 (Approx. 1000 Hrs. /Year) |
| UNPLANNED OUTAGES: | - |
| CAUSE: | - |
| INSPECTION SCHEDULE: | - |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | - |
| TIME REQUIRED: | 15 weeks |
| IMPELLER CAVITATION: | None |

| | |
|---|---|
| SEAL RING WEAR: | - |
| NOISE LEVEL-START: | 98 |
| NOISE LEVEL-RUN: | 92 (Slight cracking in suction) |
| VIBRATION: | Negligable |
| REMARKS: | - |

## GENERAL REMARKS

The Maggia Kraftwerke AG. of Locarno, the biggest hydro-electric company in southern Switzerland, has a number of power stations together forming a large-scale project for harnessing the waters of the Maggia Valley.

The two storage pumps for Peccia Power Station were ordered from Sulzer Brothers at the end of 1952. They are two-stage high-lift units, each of them built for the following mean guarantee figures:-

| | | | | |
|---|---|---|---|---|
| Discharge | 26,800 | 31,300 | 37,000 | g.p.m. |
| Total delivery head | 1,345 | 1,230 | 1,035 | ft. |
| Speed | | 1,000 | | r.p.m. |
| Input | 9,620 | 10,140 | 10,560 | kW |

After thorough study of possible layouts, it was again decided to keep the turbines and pumps separate. This affords complete freedom in the choice of the pumping capacity, which can thus be economically adapted to the widely fluctuating inflow and to the available supplies of electric power.

The two horizontal storage pumps are placed beside the turbine sets in the machine hall. Had the pumps been designed to take their water direct from the tail race of the turbines, slow-running units would have been essential on account of the high suction head. In order to permit high-speed machines to be used, the water from the tail race is therefore raised by transfer pumps. These latter, with a mean delivery of 102 ft., again do not supply the water direct to the main pumps, but to a collector running into a reservoir situated about 60 ft. above the axis of the pumps. This arrangement has several useful features to recommend it. The main pumps, for instance, also handle water from the Corgello pipe line, which is collected a little above the reservoir. This water now flows to the equalizing reservoir, after desilting, with hardly any loss of head. The transfer pumps are therefore designed for a discharge about 20% smaller than that of the main pumps, while there is no waste of head as there would be if the Corgello water had first to be piped down to the level of the tail race. The provision of an equalizing reservoir also makes the main and transfer pumps independent of each other, so that the operation of the plant is more flexible and the problem of surging after sudden stoppage of the pumps is simplified.

The two main pumps are similar in their hydraulic design to the single-flow pump of the Pragnères plant, though having only two instead of three stages.

The transfer pumps are of vertical mixed-flow design with two stages and screw-type impellers. They are installed beside the main sets and are rigidly coupled to asynchronous motors. Each pump has one shut-off only, this being a non-return valve with an oil brake.

The units adapt themselves to the delivery head, which fluctuates between 120 and 75 ft., by automatic regulation along their characteristic. As the QH-line chosen is very favorable, they operate with a good efficiency over the whole range.

For safety purposes, a quick-acting valve and a spherical seating valve supplied by de Roll of Klus are fitted on the discharge side of the main pumps. On the inlet side they are connected directly to the suction collector by way of Venturi tubes used for service measurements. During overhauls, the pipe from the equalizing reservoir is closed and the collector emptied, whereupon the Venturi tubes can be removed and replaced by cover plates.

The problem of water hammer again received careful attention. The closing movement of the quick-acting valve is exactly calculated to ensure that the pressure fluctuations remain within admissible limits even if the pumps cut out unexpectedly. The danger of the main pumps running in reverse is here almost completely eliminated. The hydraulic conditions also permit the same closing movement to be used for the normal shutting-down of the pumping sets by switching off the motor when the valve has been closed. This results in a simplification of the control equipment.

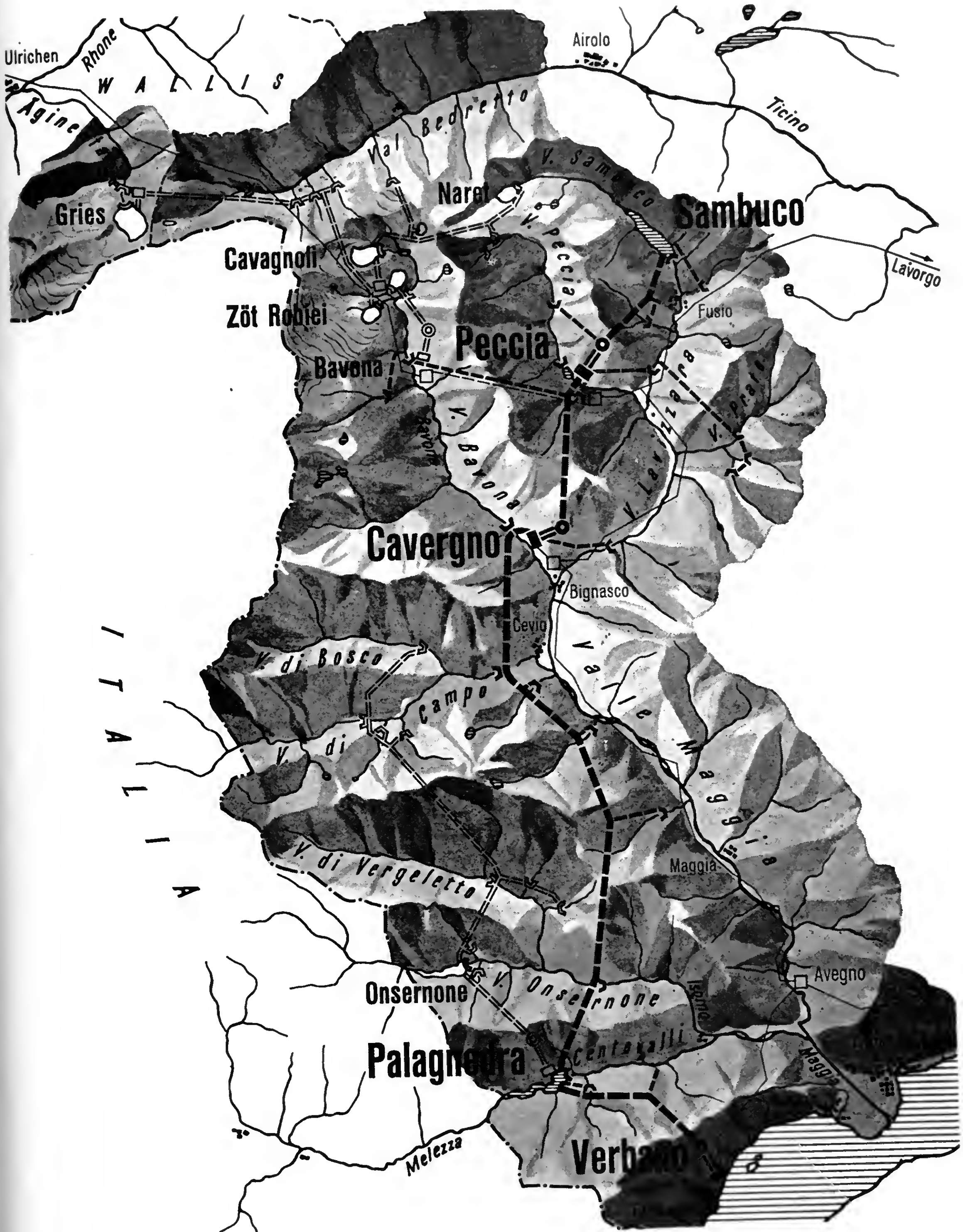



Fig. 9-1 - Plan of Maggia System


Fig. 9-2 - Interior view of Plant.

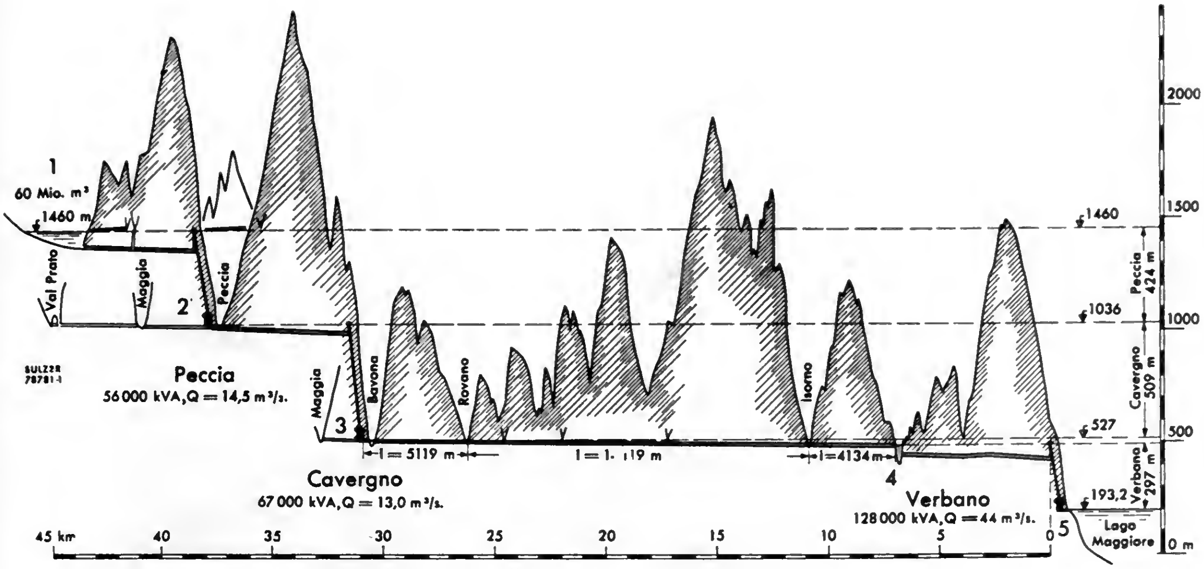
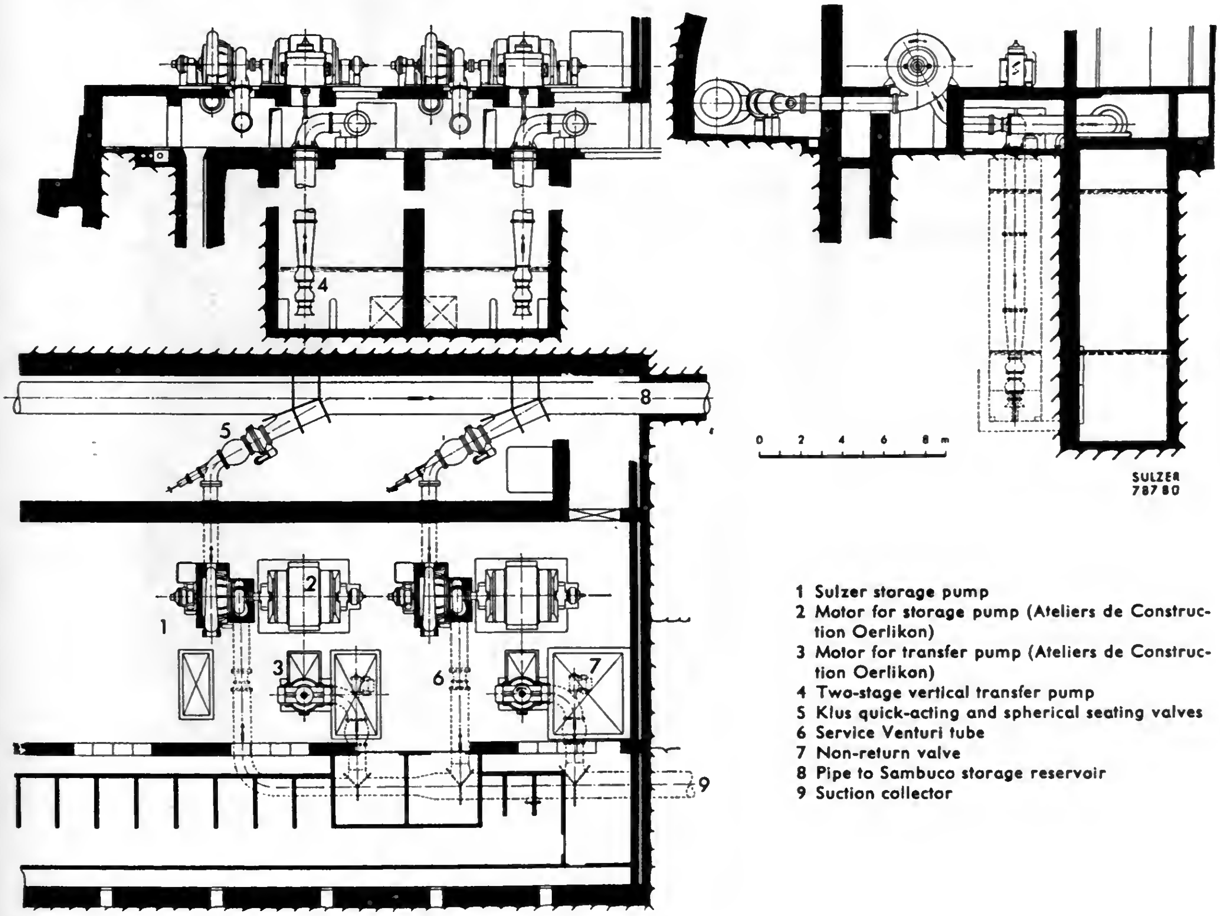



Fig. 9.3 - Profile of Maggia System




1 Sulzer storage pump
2 Motor for storage pump (Ateliers de Construction Oerlikon)
3 Motor for transfer pump (Ateliers de Construction Oerlikon)
4 Two-stage vertical transfer pump
5 Klus quick-acting and spherical seating valves
6 Service Venturi tube
7 Non-return valve
8 Pipe to Sambuco storage reservoir
9 Suction collector

Fig. 9.4 - Plan of Peccia Plant

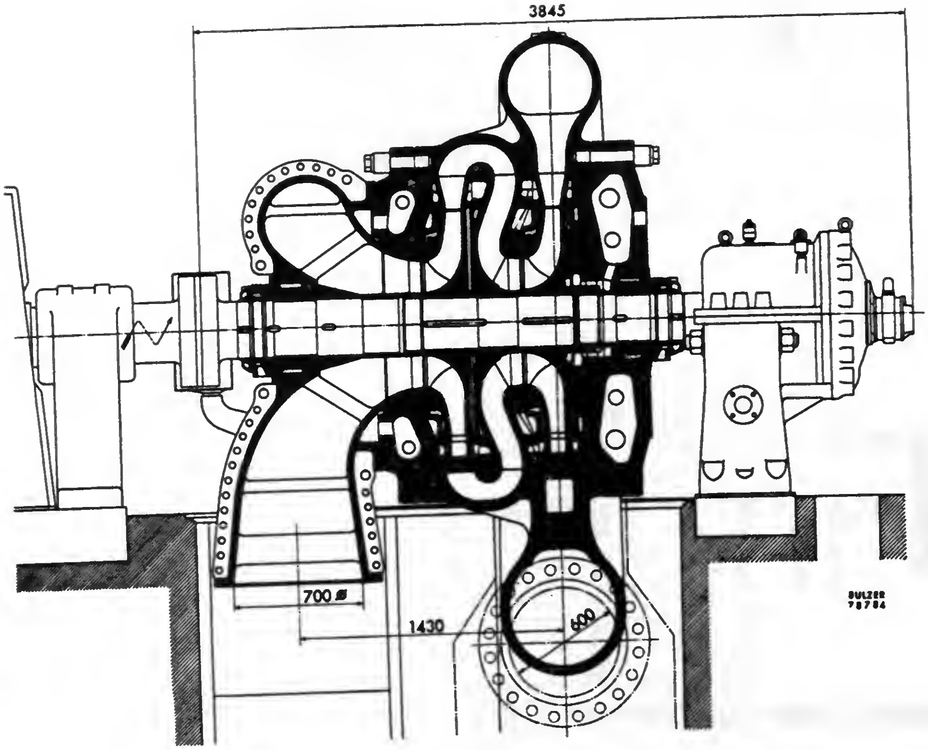



Fig. 9-5 - Section of Peccia Pump

Fig. 9.6 (G3-22) Suction end of Pump

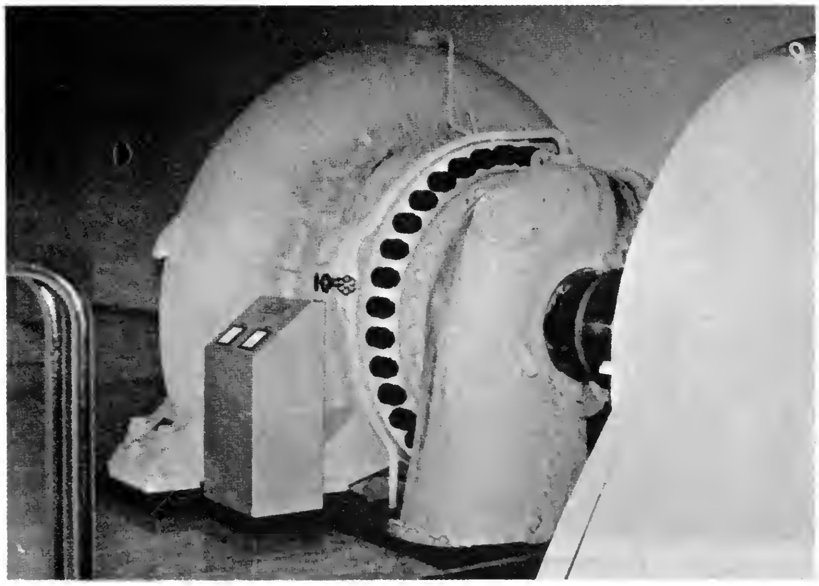


Fig. 9-7 (G3-23) Drive end of Pump

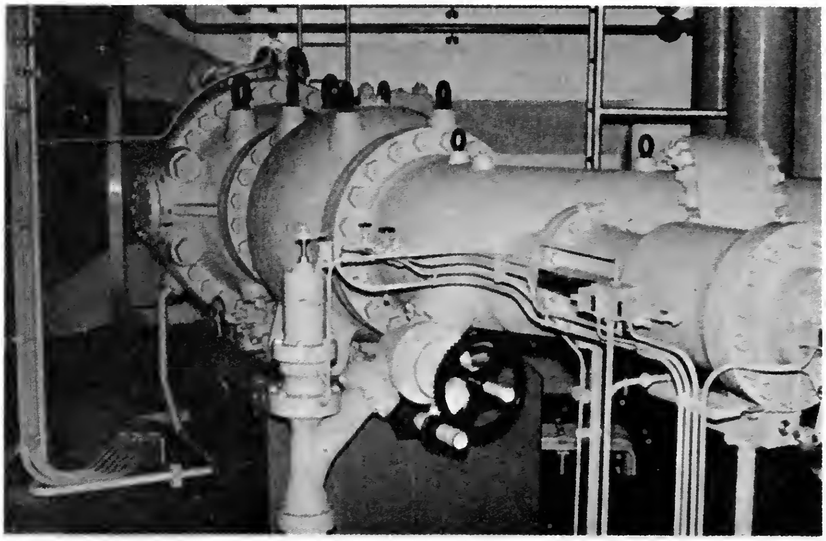


Fig. 9-8 (G3-25) Needle Valve on Discharge

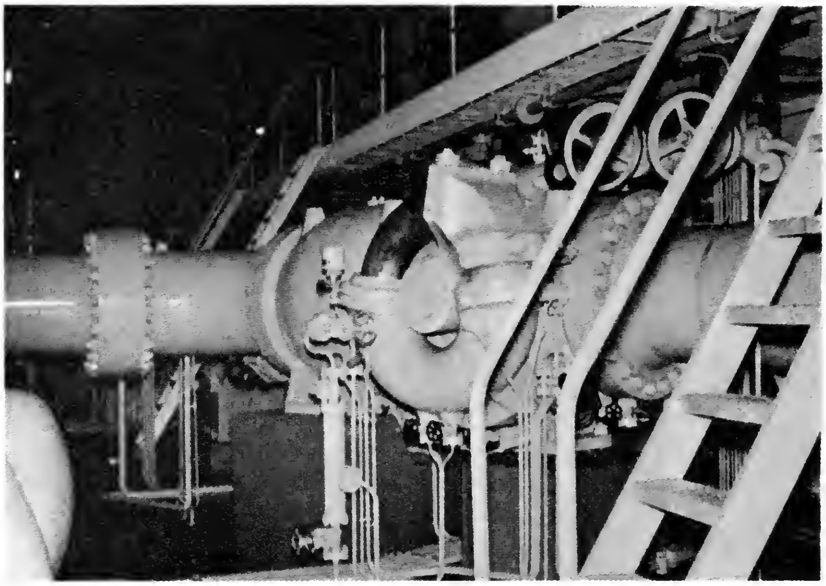


Fig. 9-9 (G3-24) Von Roll Spherical Valve on Discharge

## Vibration Records

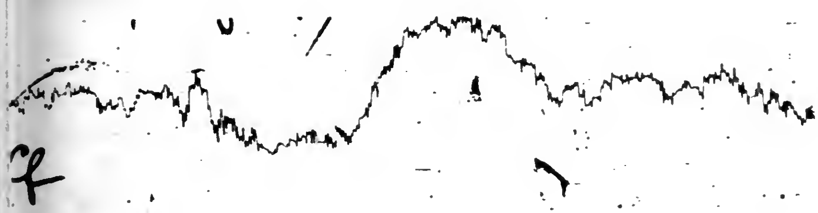
Maggia Kraftwerke AG, Locarno, Switzerland

**Plant** : Peccia (underground power house)

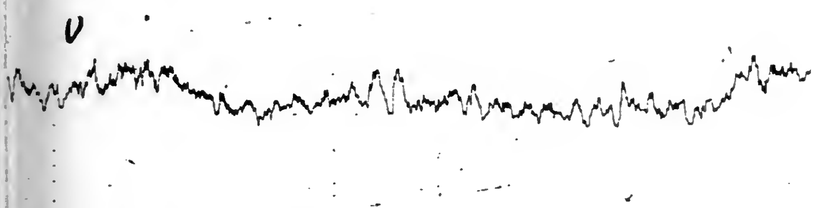
**Units** : two, 2-stage, single flow, horizontal pumps; 13, 600 HP, 83.7 cfs, 1230 ft, 1000 RPM

**Records-taken** : July 9, 1964

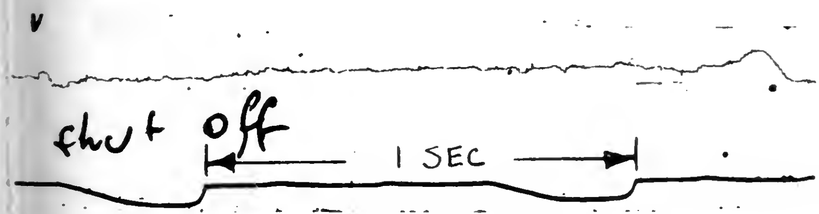
**Unit 2**



1. Shaft, coupling side - discharge valve closed



2. Shaft, bearing side - discharge valve closed




3. Bearing, axial - discharge valve closed

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 9000 | .0015 |
| 9000 | .0007 |
| ---- | less than .0002 |

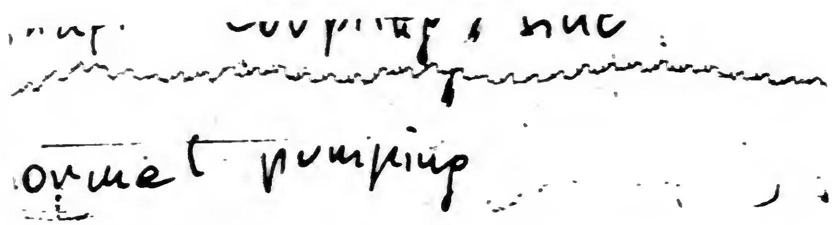
Figure 9-10

<u>Vibration Records (cont.)</u>

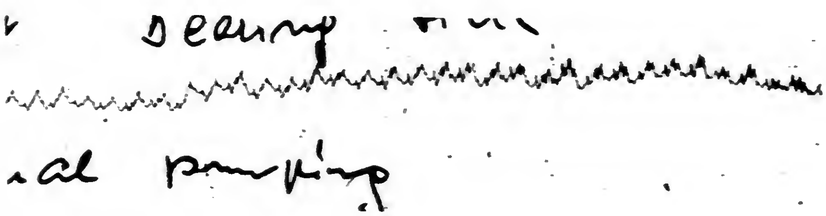
Maggia Kraftwerke AG, Locarno, Switzerland

<u>Plant</u> : Peccia (underground power house)

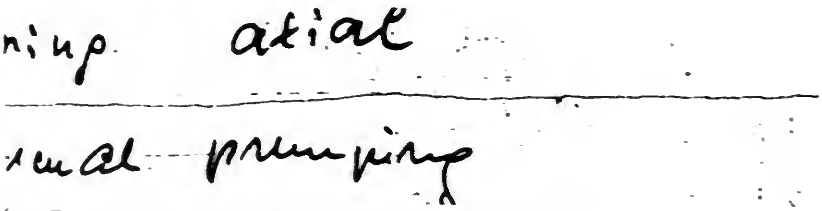
<u>Unit 2</u> (cont.)



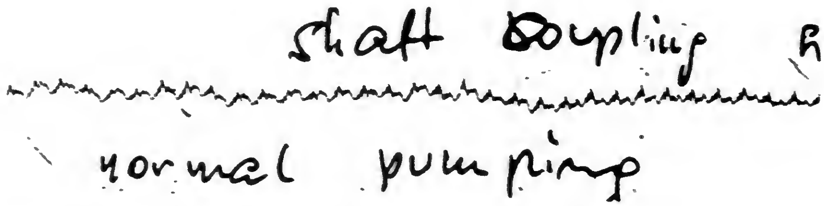

4. Shaft, coupling side - normal pumping



5. Shaft, bearing side - normal pumping




6. Bearing, axial - normal pumping




7. Shaft, coupling side - normal pumping

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 9000<br>1020 | .0004<br>.0008 |
| 18,000<br>1020 | .0005<br>.0019 |
| --- | less than .0002 |
| 18,000<br>1020 | .0005<br>.0019 |

Figure 9-11

Maggia Kraftwerke AG, Locarno, Switzerland

Plant : Peccia (underground power house)

Unit 2 (cont.)

spiral casing

normal pumping

| | Frequency c.p.m. | Average Amplitude inches |
|---|---|---|
| 8. Volute casing - normal pumping | --- | less than .0002 |
| 9. Suction elbow - normal pumping | --- | less than .0002 |
| 10. Volute casing - discharge valve closed | --- | .0002 |

spiral casing

shut off

Figure 9-12

PUMPS:

| | |
|---|---|
| TYPE: | 9-stage, single suction, horizontal |
| MANUFACTURER: | Escher-Wyss |
| SIZE DISCHARGE: | - |
| SIZE SUCTION: | - |
| RPM: | 1000 |
| CFS: | 16.5 |
| HEAD: | 2953 |
| H.P. REQUIRED: | 6800 |
| N s.: | 1120 |
| INSTALLED: | 1925 |
| HRS. OF OPERATION | 82,000 |
| MIN. SUBMERGENCE: | - |
| NORMAL SUBMERGENCE: | -6.6 |
| MAX. SUBMERGENCE: | - |
| REMARKS: | - |
| PUMP EFFICIENCY: | 81% |

PLANT NAME: TREMORGIO

REPORT NO.: 11

| | |
|---|---|
| LOCATION-ALTITUDE: | Near Rodi Fiesso, Switzerland - 6000' |
| OWNER: | Canton of Tessin |
| ADDRESS | Switzerland |
| TYPE OF PLANT: | Surface |
| SERVICE | - |
| TYPE OF WATER: | - |
| UNITS INSTALLED: | Two 9-state horizontal pumps, both driven through gears by one motor and turbine. |
| HORSEPOWER: | 6,800 |
| CFS: | 16.5 |
| STATIC HEAD: | 2950' |
| PLANT STARTED: | 1925 |
| VISITED BY: | H. Gartmann - Ó. Hartmann - R.E. Westman |
| DATE: | July 10, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Chief Operator |
| REMARKS: | - |

PLANT NAME: LIMBERG

REPORT NO.: 12

| | |
|---|---|
| LOCATION-ALTITUDE: | Western Austria 5300' - (Just over the Swiss Border) |
| OWNER: | Tauernkraftwerke, A. G. |
| ADDRESS: | Salsburg, Austria |
| TYPE OF PLANT: | Surface - Pump Storage |
| SERVICE | Utility Power |
| TYPE OF WATER: | Glacial Melt |
| UNITS INSTALLED: | 2 - Horizontal - 2-stage, double-flow (Impulse turbines on same shaft) |
| HORSEPOWER: | 72,600 - 85,200 (Metric) |
| CFS: | 400 - 585 |
| STATIC HEAD: | 1192' (Max.) |
| PLANT STARTED: | 1957 |
| VISITED BY: | Gartmann-Hartmann-Westman |
| DATE: | July 13, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Dr. A. Wobornik<br>M. F. Hofer |
| REMARKS: | Pumps pick up water from Wasserfallboden at 5500' and return it to Mooserboden Lake, about 2.2 miles to the South at an elevation of 6500'. |

PUMPS:

| | | |
|---|---|---|
| TYPE: | Horizontal - 2-stage, double-suction | |
| MANUFACTURER: | Escher Wyss | |
| SIZE DISCHARGE: | 59" (1500 mm) | |
| SIZE SUCTION: | 2 x 53" (1350 mm) | |
| RPM: | 500 | |
| CFS: | 586 | 402.5 |
| HEAD: | 1065' | 1375' |
| H.P. REQUIRED: | 79,700 | 69,750 |
| N s.: | 1635 | 1114 |
| INSTALLED: | 1957 (Turbine 1955) | |
| HRS. OF OPERATION | I - 7200 | II - 7400 |
| | (848 to 1260 per year) | |
| MIN. SUBMERGENCE: | 59' (once/year - in Spring) | |
| NORMAL SUBMERGENCE: | - | |
| MAX. SUBMERGENCE: | 394' | |
| REMARKS: | Pumps have 140 to 170 psi pressure on suction. | |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | No Data |
| MODEL ACTUAL: | " " |
| PROTOTYPE-GUARANTEED: | 88 - 89 (at 410.7 MTS) |
| PROTOTYPE-ACTUAL: | No. I- 90.14 - No. II- 88.2 |
| METHOD OF TEST: | Current meters in discharge (After 6 yrs. changed from 90.14 to 88.0) |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 59" - (1500 MTS) |
| DIAMETER IMPELLER: | 90" - (2300 mm) |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 23.6" |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | 1st stage - 13% Cr. - 2nd stage - manganese steel |
| MATERIAL IMPELLER RINGS: | Manganese steel (double step) |
| MATERIAL-CASING RINGS: | " " |
| RADIAL CLEARANCE: | .90 mm (1.3 after 10 yrs.) |
| MATERIAL BALANCING RINGS: | None |
| MATERIAL INTERSTAGE SEAL: | Babbitt against shaft |
| RADIAL CLEARANCE: | 0.75 mm |
| MATERIAL DIFFUSER: | Manganese steel (also return passages) |
| BEARING: | 23.6" & 22.2" (outer end) |
| THRUST BEARING: | Double acting Mitchell type on both sides of outer bearing. |

| | |
|---|---|
| TYPE OF PACKING: | Mechanical |
| MATERIAL OF PACKING: | Carbon Rings |
| MATERIAL OF SLEEVE: | Cr. Plated (was bronze) |
| CLEARANCE: | None |
| REMARKS: | Backoff bushing originally bronze and steel -- now Babbitt (stationary) and Cr. plate (rotating). Seal water cleaned in pebble filter. |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Horizontal-synchronous - exciter on motor shaft next to rotor. |
| MANUFACTURER: | Elin |
| H.P.: | 83,000 (62,000 kva) |
| R.P.M.: | 500 |
| VOLTAGE: | 10,000 |
| STARTING: | Start by Turbine |
| REMARKS: | Units have small impulse turbine (Bremsturbine) for braking the unit. |

TURBINE:

| | |
|---|---|
| TYPE: | Francis |
| MFG.: | Escher Wyss |
| HEAD: | 1190' ± |
| R.P.M.: | 500 |
| H.P.: | 77,700 P.S. |
| REMARKS: | Turbine efficiency dropped from 92.8 to 92.4 in 10 years. |

## VALVES:

| | |
|---|---|
| INTAKE: | None |
| TYPE: | (Must evacuate suction Penstock to service pump) |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | - |

| | |
|---|---|
| DISCHARGE: | |
| TYPE: | Needle |
| MANUFACTURER: | Von Roll |
| SIZE: | 63" (1600 mm) |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | Water Pressure |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | Valve had bronze seats (both). Had trouble after five years. Prefer bronze against stainless steel as used on turbines. |

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | One - 8.2' to 9.5' |

LENGTH: About 2200' at steep incline, then into a 11' tunnel about 14,720' long.

| | |
|---|---|
| MATERIAL: | - |
| TYPE OF UPPER GATE: | - |
| SURGE TANK: | - |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Not good - contains some glacial silt. |
| Ph: | |
| HARDNESS: | |
| REMARKS: | Quality varies - contains sharp particles. |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | In Summer only. |
| STARTS/DAY: June 15-July ) Aug. 15-Sep. ) | 2/day June 1/day Winter 1/10/Day |
| HOURS OF OPERATION: | I- 5073 II- 4700 III- 5772 (as of July 22, 1964) |
| UNPLANNED OUTAGES: | - |
| CAUSE: | - |
| INSPECTION SCHEDULE: | - |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | One per year |
| TIME REQUIRED: | One week (two days for wearing rings) |
| IMPELLER CAVITATION: | None |

| | |
|---|---|
| SEAL RING WEAR: | Relatively little |
| NOISE LEVEL-START: | 97 - 99 - 100 - 105 |
| NOISE LEVEL-RUN: | A-95; B-97; C-98-102 |
| VIBRATION: | - |
| REMARKS: | Very little trouble or maintenance. Backoff bushing seized once. Needed 20 days to install a new one. |

## GENERAL REMARKS

The Tauernkraftwerke in Austria produce a total of approximately 300,000 H.P. in their Kaprun plant, which utilizes the first head stage and is equipped with four Escher Wyss impulse turbines. Further utilization of the very extensive catchment area of the Grossglockner was then considered, namely, realization of the upper Limberg stage. Considerations connected with energy economy led to the installation of two storage pumps, the order for which was entrusted to Escher Wyss. These units are the large pumps, designed for an average manometric delivery head of 385 m. and each for a discharge of 13,200 lit./sec. at 500 RPM with a maximum unit input of approximately 85,000 H.P. These pumping sets which are arranged horizontally, deal with pressures on the inlet side varying between 14 and 96 m., depending on the height of the water level in the artificial lake of Wasserfallboden from which they lift water into the Moserboden lake. On the same shaft of each unit there is an Escher Wyss Francis turbine of about 77,000 H.P. output which utilizes the water in the opposite direction.

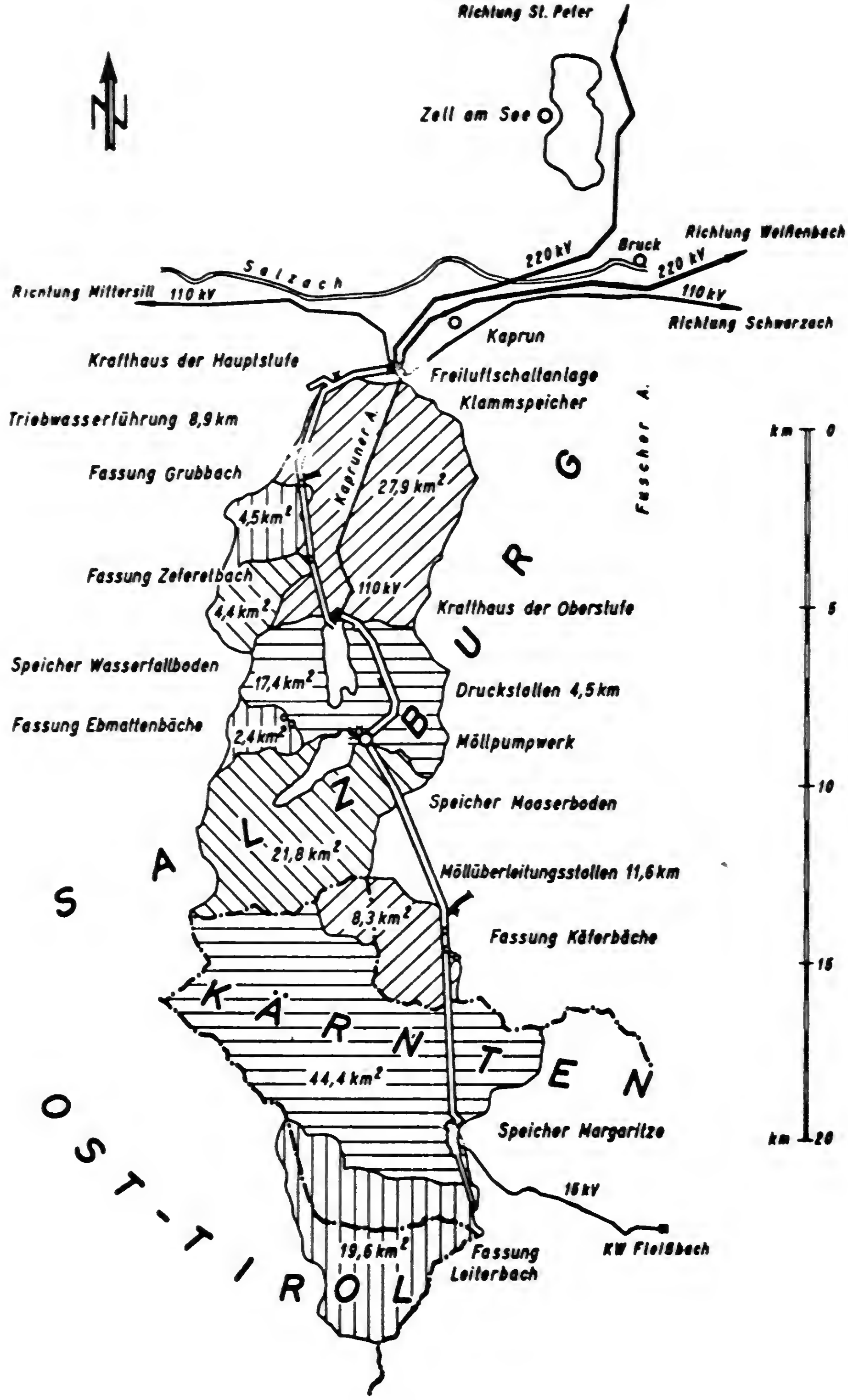



Fig. 12. 1 - Map of Tauern System.

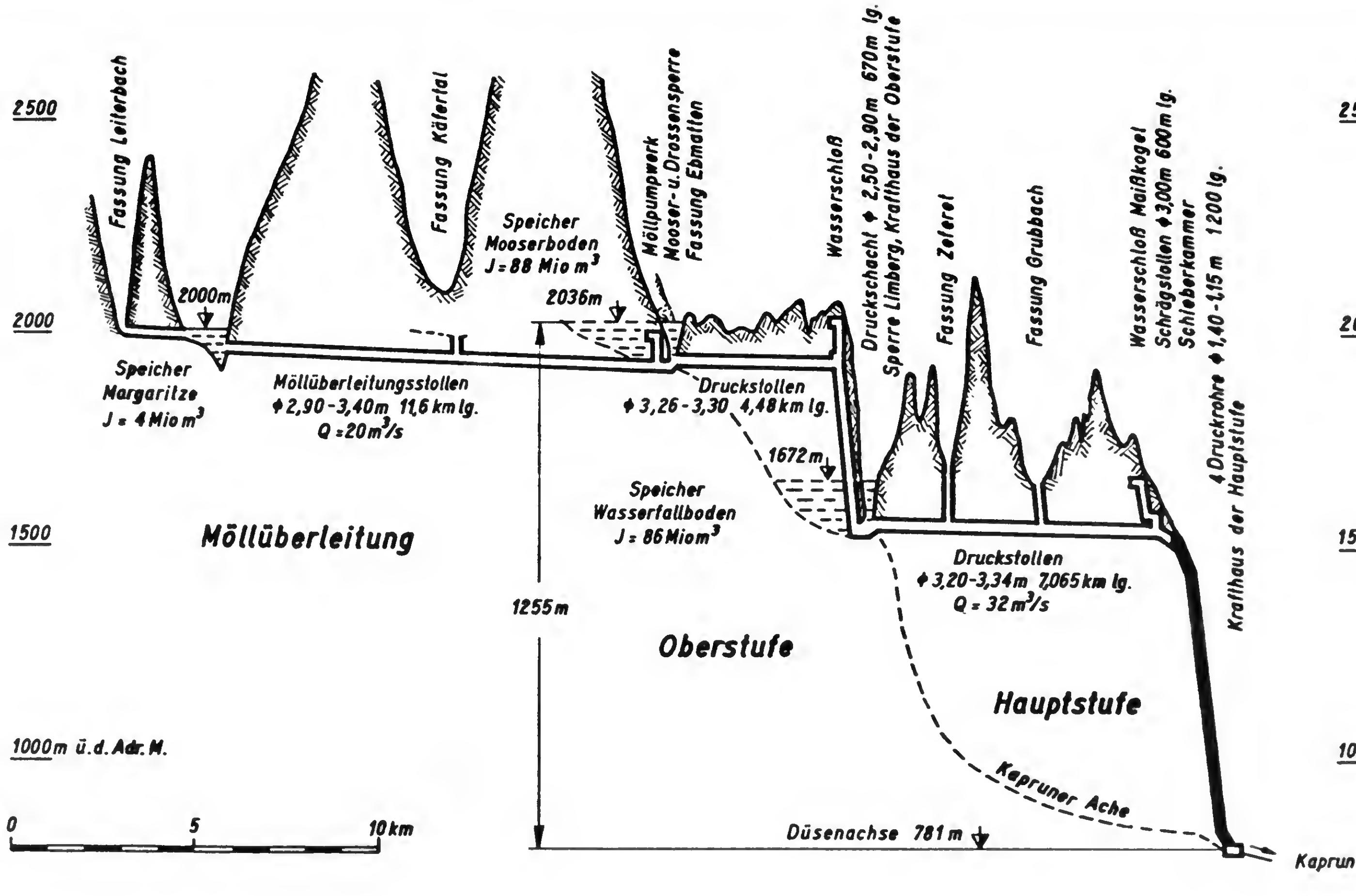



Fig. 12. 2 - Profile of Tauern System

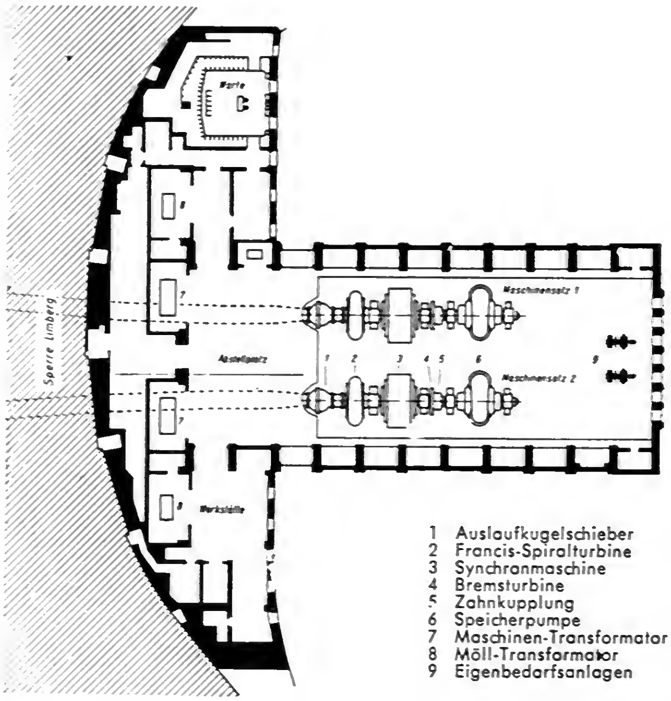



Fig. 12.3 - Plan of Pump House

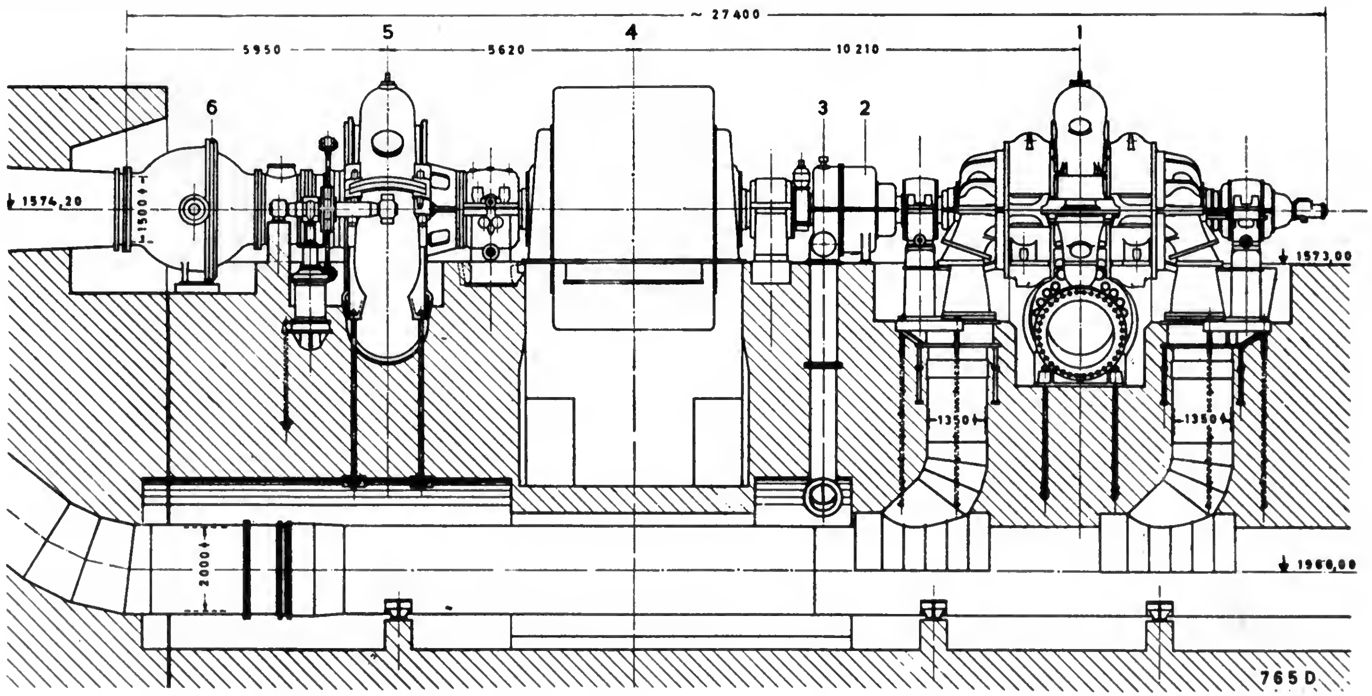



Fig. 12.4 - Section showing machinery arrangement:

1. Pump
2. Gear Coupling
3. Braking Turbine
4. Motor Generator
5. Francis Turbine
6. Turbine Outlet Valve

Fig. 12.5. (WR-6) View of Dam and Station

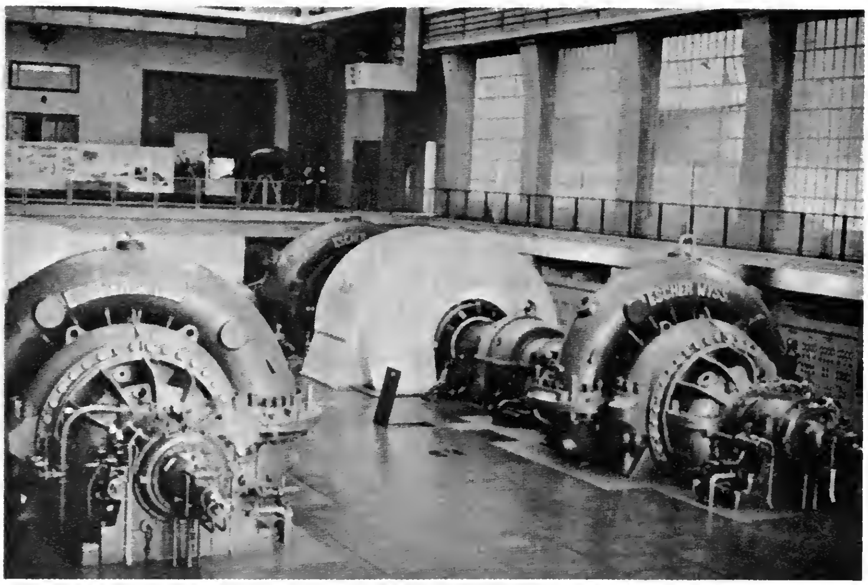


Fig. 12.6 (G4-3) Station Interior

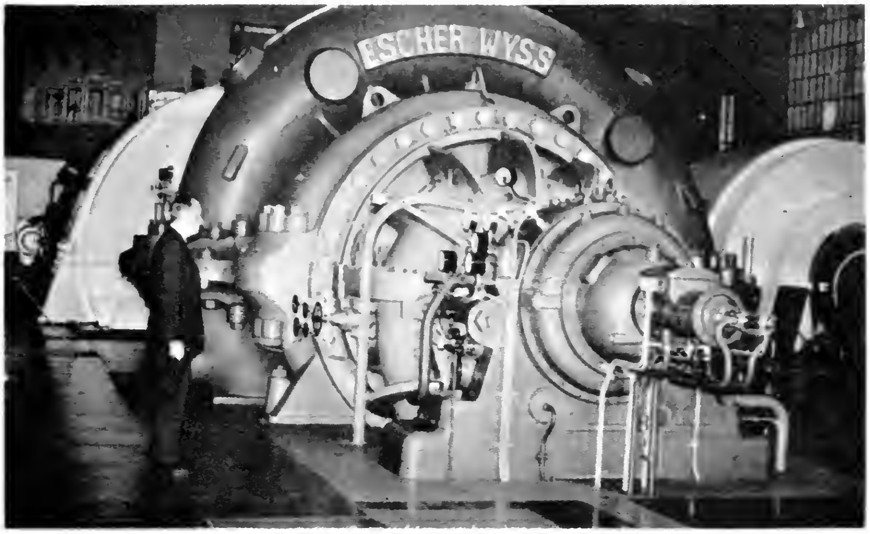



Fig. 12.7 (G4-5) Close-up of Storage Pump

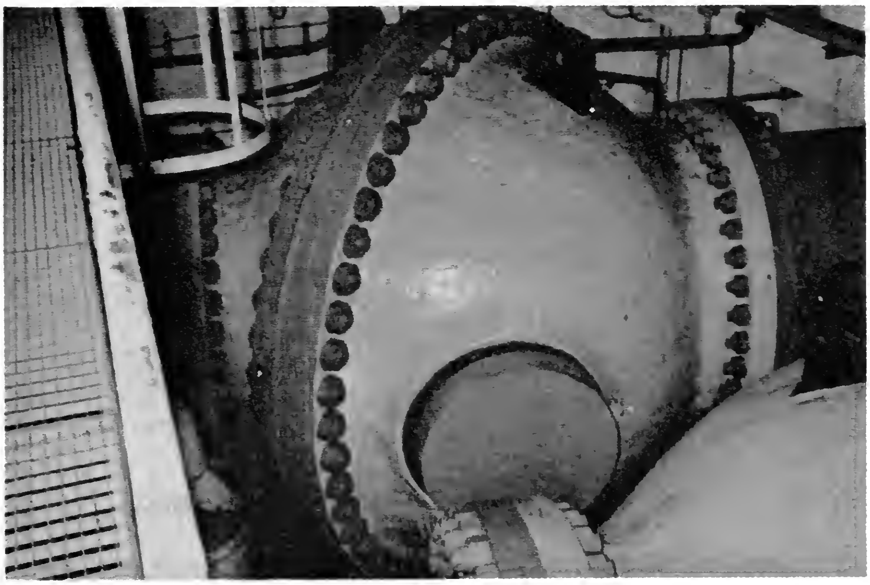


Fig. 12.8 (W4-19) Spherical Valve

## Vibration Records

Tauernkraftwerke AG, Salzburg, Austria

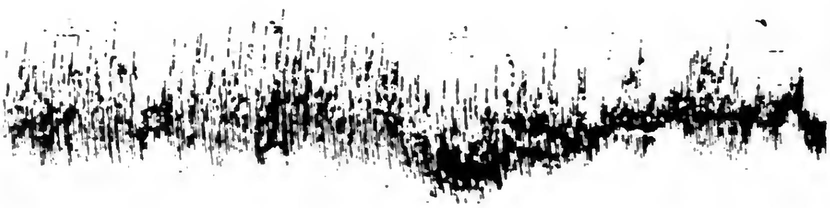
Plant : Limberg (surface power house)

Units : two, 2-stage, double flow, horizontal pumps; 79,000 HP, 459 cfs, 1280 ft, 500 RPM

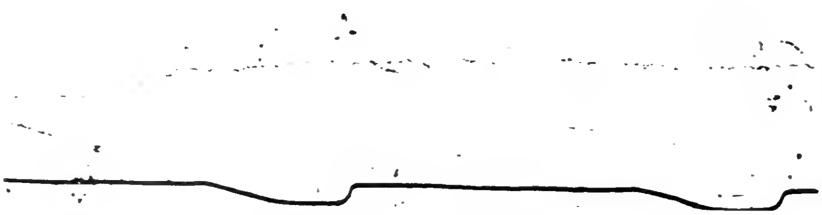
Records-taken : July 13, 1964

Unit 1


1. Brake impulse turbine casing - Francis turbine slowing down



2. Brake impulse turbine casing - Francis turbine slowing down



3. Pump casing - pump operation against closed discharge valve

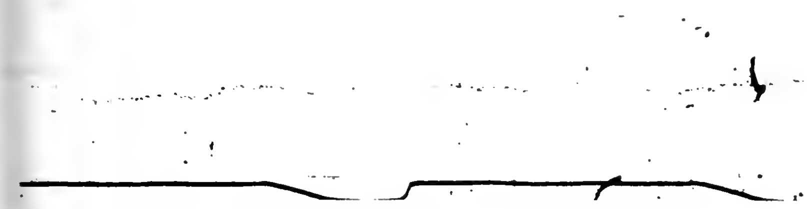
| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 12,000 | .0050 |
| 9000 | .0060 |
| 8000 | .0002 |

Figure 12-9

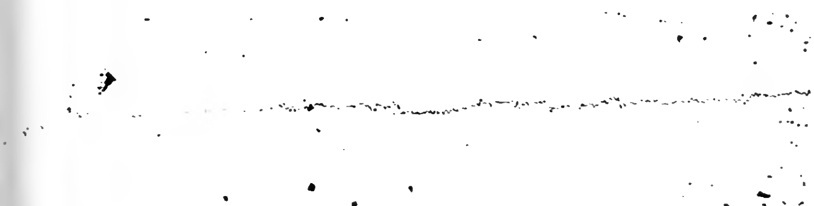
Tauernkraftwerke AG, Salzburg, Austria

Plant : Limberg (surface power house)

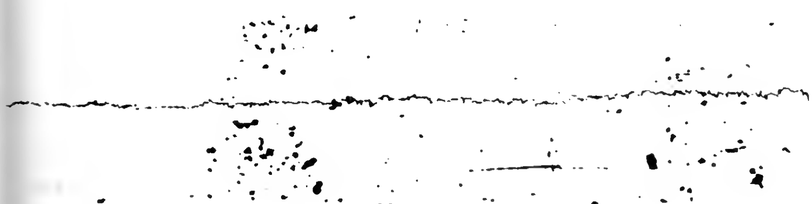
Unit 1 (cont.)



4. Pump casing - discharge valve closed



5. Pump casing - discharge valve closed



6. Pump casing - discharge valve closed

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 9000 | .0004 |
| 4800 | .0006 |
| 9000 | .0004 |

Figure 12-10

## Vibration Records (cont.)

Tauernkraftwerke AG, Salzburg, Austria

Plant : Limberg (surface power house)

### Unit 1 (cont.)

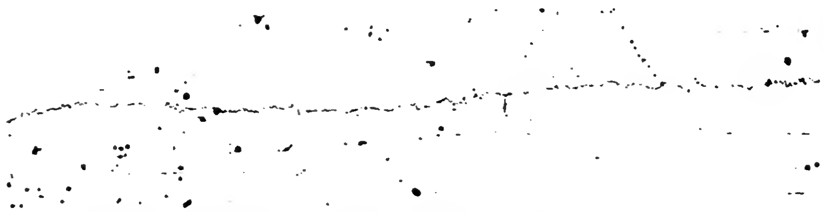
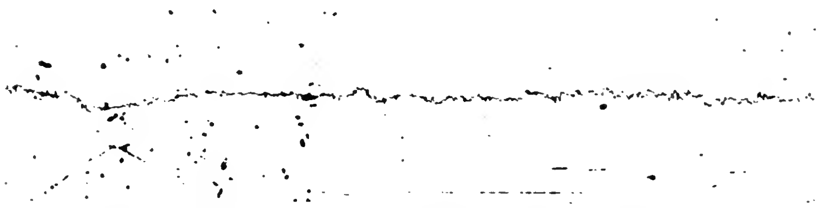
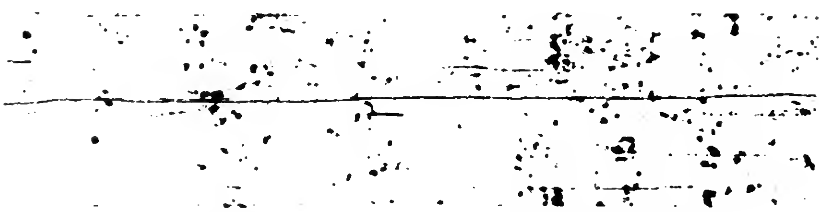
| | Frequency c.p.m. | Average Amplitude inches |
|---|---|---|
|  7. Pump casing - discharge valve closed | 6000 | .0006 |
|  8. Pump casing - discharge valve closed | 10, 800 | .0005 |
|  9. Volute casing - normal pump operation | ---- | less than .0002 |

Figure 12-11

PLANT NAME: MÖLL

REPORT NO.: 13

| | |
|---|---|
| LOCATION-ALTITUDE: | Western Austria - 6360' |
| OWNER: | Tauernkraftwerke, AG. |
| ADDRESS: | Salzburg, Austria |
| TYPE OF PLANT: | Underground |
| SERVICE | Transfer of water from Mooserboden Reservoir to Margaritze Reservoir. |
| TYPE OF WATER: | Some Glacial Silt |
| UNITS INSTALLED: | Two, single-stage, double-suction horizontal pumps. |
| HORSEPOWER: | 8000 |
| CFS: | 318 |
| STATIC HEAD: | Variable from 0' to 196' |
| PLANT STARTED: | 1955 |
| VISITED BY: | Gartmann - Hartmann - Westman |
| DATE: | July 14, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Dr. A. Wobornik |
| REMARKS: | - |

PUMPS:

| | | |
|---|---|---|
| TYPE: | Single-Stage, Double-Suction, Horizontal | |
| MANUFACTURER: | Maschinenfabrik, Andritz (Austria) | |
| SIZE DISCHARGE: | 55" (1400 mm) | |
| SIZE SUCTION: | 2 x 43.3" (1100 mm) | |
| RPM: | 495 | |
| CFS: | 193 | 490 |
| HEAD: | 226 | 97.7' |
| H.P. REQUIRED: | 5700 | 6200 |
| N s.: | 1790 | 5500 |
| INSTALLED: | 1955 | |
| HRS. OF OPERATION | - | |
| MIN. SUBMERGENCE: | 0' | |
| NORMAL SUBMERGENCE: | - | |
| MAX. SUBMERGENCE: | 59' | |
| REMARKS: | During part of the year the level of the forebay may be higher than that of the afterbay. | |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | - |
| PROTOTYPE-GUARANTEED: | - |
| PROTOTYPE-ACTUAL: | 88% (Estimated) |
| METHOD OF TEST: | - |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 55" (1400 mm) |
| DIAMETER IMPELLER: | 55.7" |
| DIAMETER EYE: | 41" |
| DIAMETER SHAFT: | 15.6" (at impeller) |
| MATERIAL CASING: | Welded steel volute |
| MATERIAL IMPELLER: | 12% Chrome Steel |
| MATERIAL IMPELLER RINGS: | - |
| MATERIAL-CASING RINGS: | - |
| RADIAL CLEARANCE: | - |
| MATERIAL BALANCING RINGS: | - |
| MATERIAL INTERSTAGE SEAL: | - |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | - |
| BEARING: | Three bearings (two on motor - one on pump) Solid Coupled. |
| THRUST BEARING: | Double active disc and shoes in outboard bearing. |

| | |
|---|---|
| TYPE OF PACKING: | - |
| MATERIAL OF PACKING: | Four carbon rings - grease lubricated. |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Horizontal - Induction |
| MANUFACTURER: | ELIN, AG (Weiz, Austria) |
| H. P.: | 8000 |
| R. P. M.: | 495 |
| VOLTAGE: | 10,000 |
| STARTING: | Direct - Across-the-line closed discharge. |
| REMARKS: | - |

TURBINE:

| | |
|---|---|
| TYPE: | None |
| MFG.: | - |
| HEAD: | - |
| R. P. M.: | - |
| H. P.: | - |
| REMARKS: | - |

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | Spherical - Two per pump |
| MANUFACTURER: | Österr Armaturen AG. (Vienna) |
| SIZE: | 43. 3" |
| OPERATION: | Oil Hydraulic |

DISCHARGE:

| | |
|---|---|
| TYPE: | Needle |
| MANUFACTURER: | Österr Armaturen, AG. |
| SIZE: | 55" |
| OPERATION: | |
| OPENING: | Oil - Hydraulic |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | - |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | One - 9. 5' - 11. 1' (Tunnel) |
| LENGTH: | 7. 25 miles |

| | |
|---|---|
| MATERIAL: | Tunnel |
| TYPE OF UPPER GATE: | None |
| SURGE TANK: | None |
| REMARKS: | - |

| | |
|---|---|
| WATER QUALITY: | Contains glacial silt, but solids settle out. |
| GENERAL: | - |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | - |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | Seasonal - Intermittent |
| STARTS/DAY: | - |
| HOURS OF OPERATION: | Unknown |
| UNPLANNED OUTAGES: | - |
| CAUSE: | - |
| INSPECTION SCHEDULE: | - |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | - |
| TIME REQUIRED: | - |
| IMPELLER CAVITATION: | No |

| | |
|---|---|
| SEAL RING WEAR: | No |
| NOISE LEVEL-START: | A- 93; B-95; C- 100 |
| NOISE LEVEL-RUN: | A-70; B-73; C- 75 |
| VIBRATION: | Very small - See chart |
| REMARKS: | - |

## GENERAL REMARKS

The Möll pumping plant is located in the upper reaches of the Tauern System at an elevation of approximately 6500 ft. It is an underground plant, containing two horizontal single-stage, double-flow pumps. The pumps are designed to transfer water from a reservoir approximately eight miles distant, to a normally higher elevation reservoir near the pumps. Seasonal conditions may, at times, allow the flow to take place without pumping, therefore, the service is intermittent.

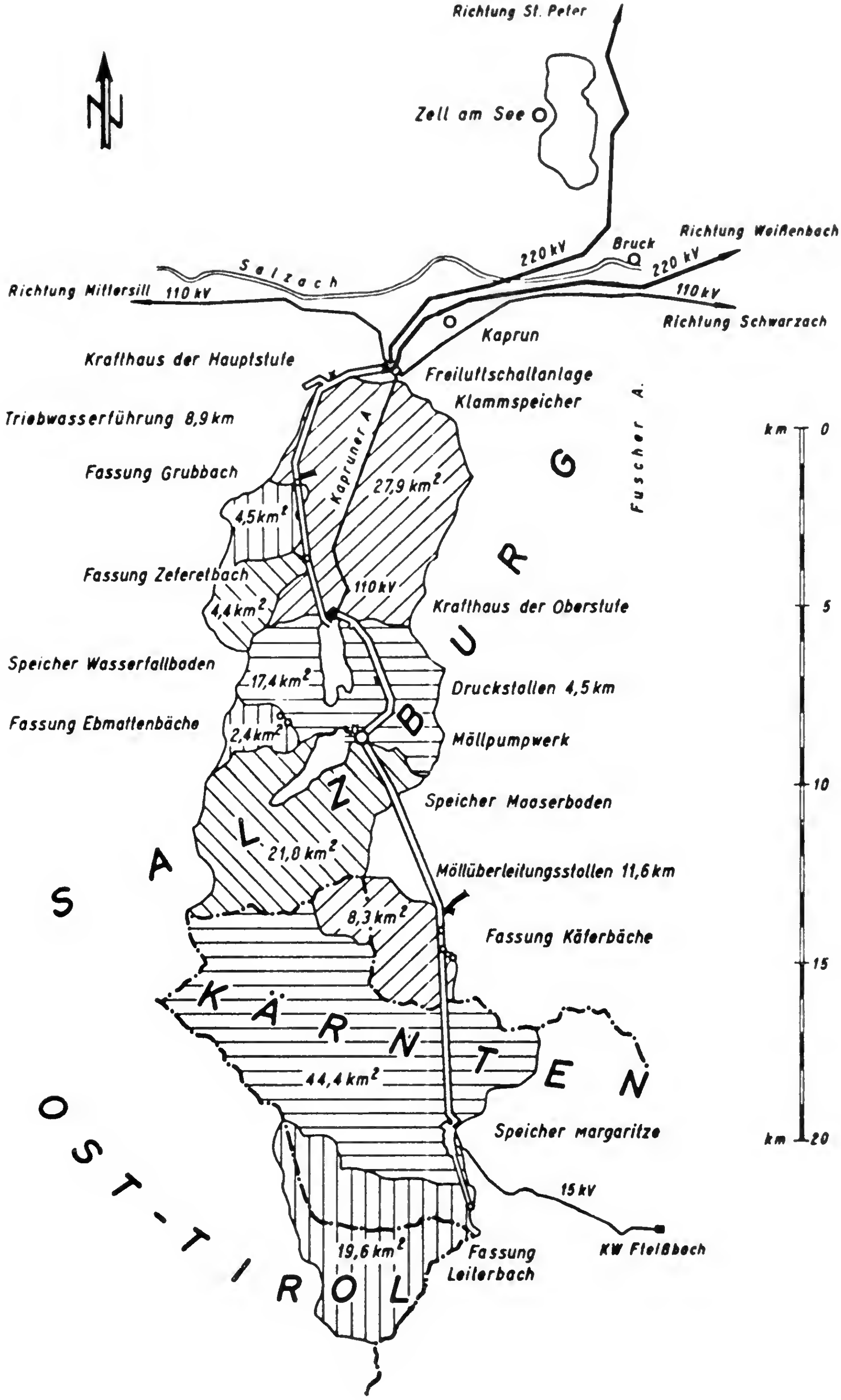



Fig. 13-1 - General plan of Tauern System

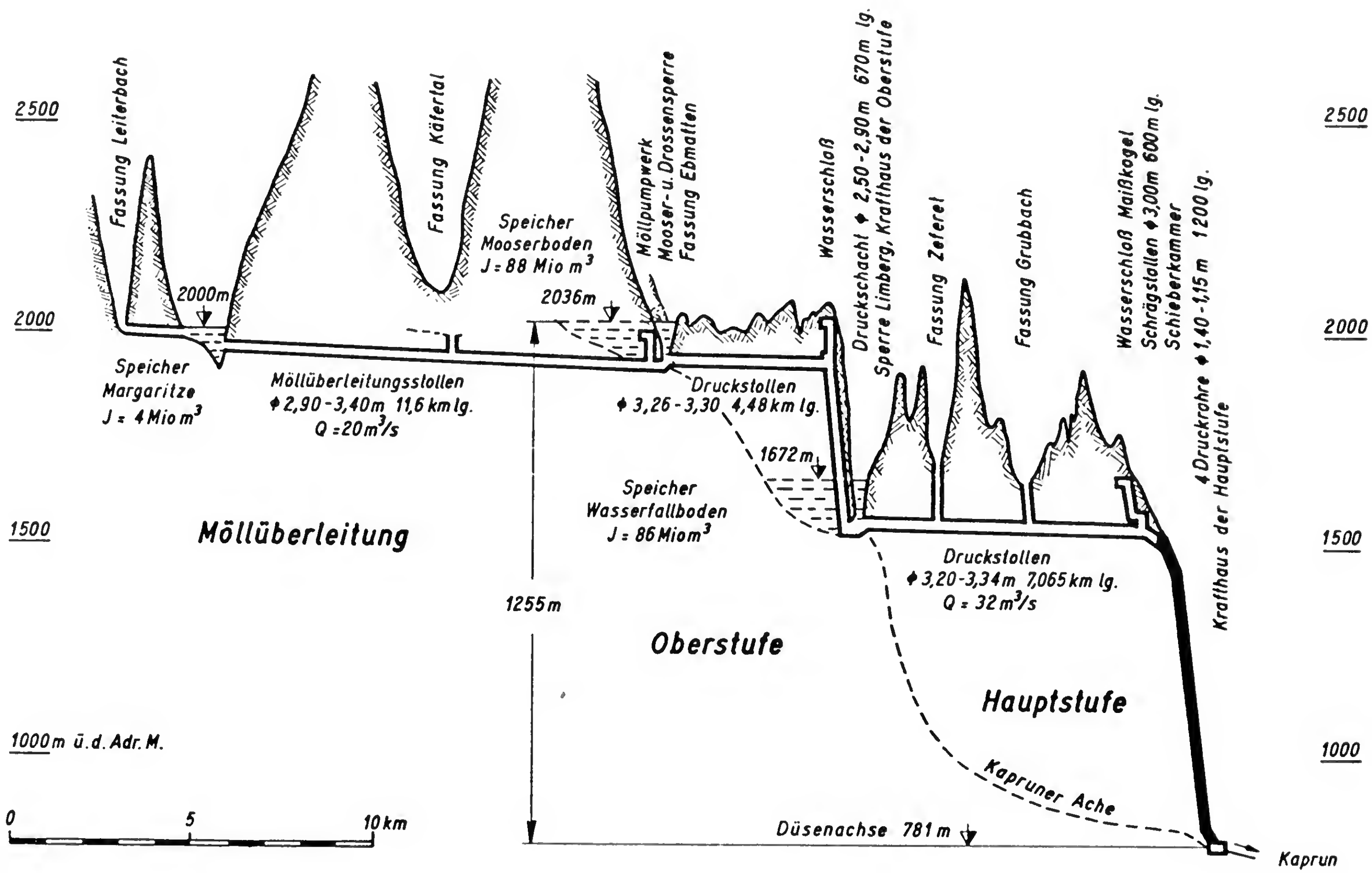



Fig. 13-2 - Profile of System

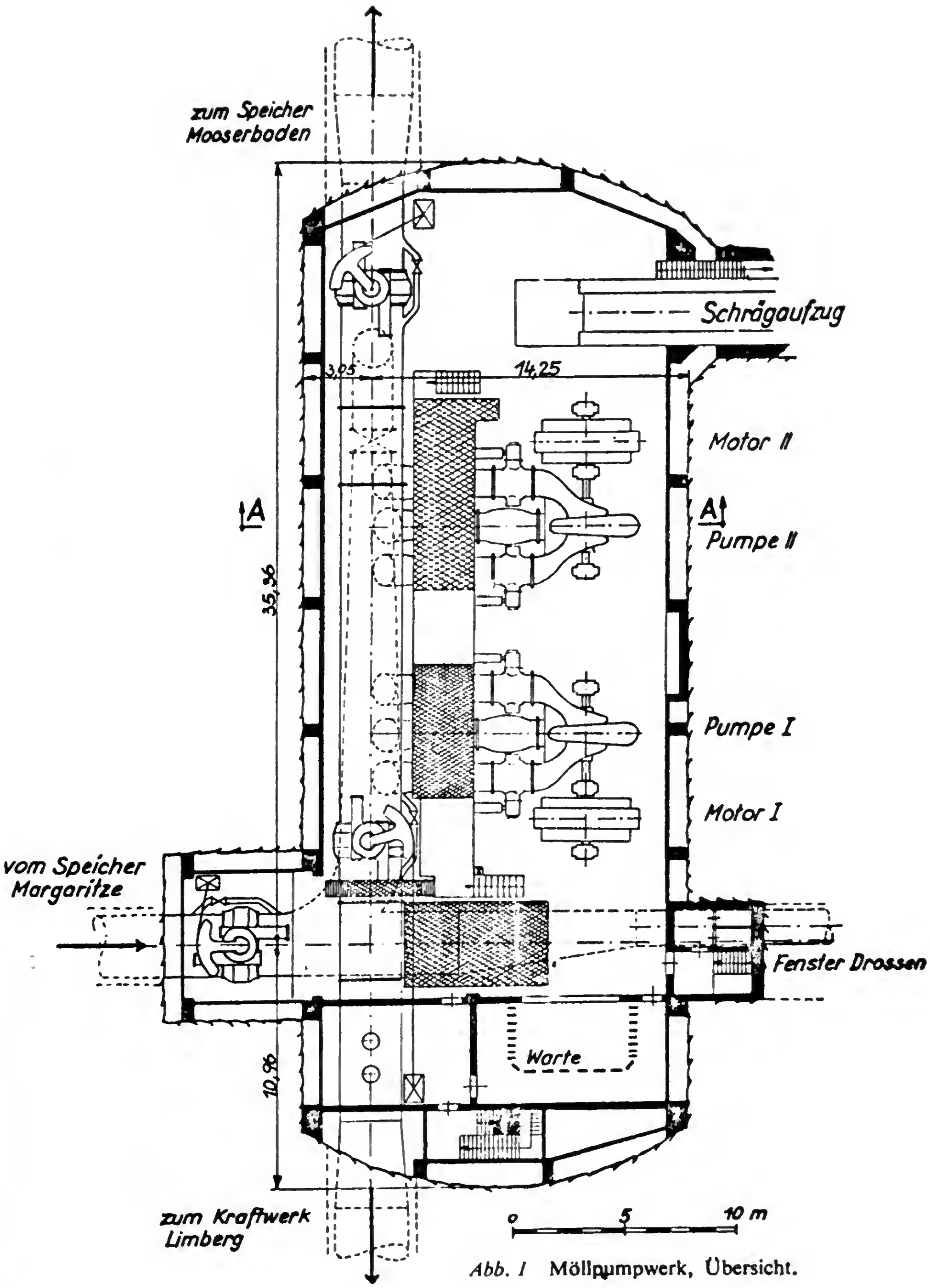


*Abb. 1* Möllpumpwerk, Übersicht.

Fig. 13.3 - Plan of System

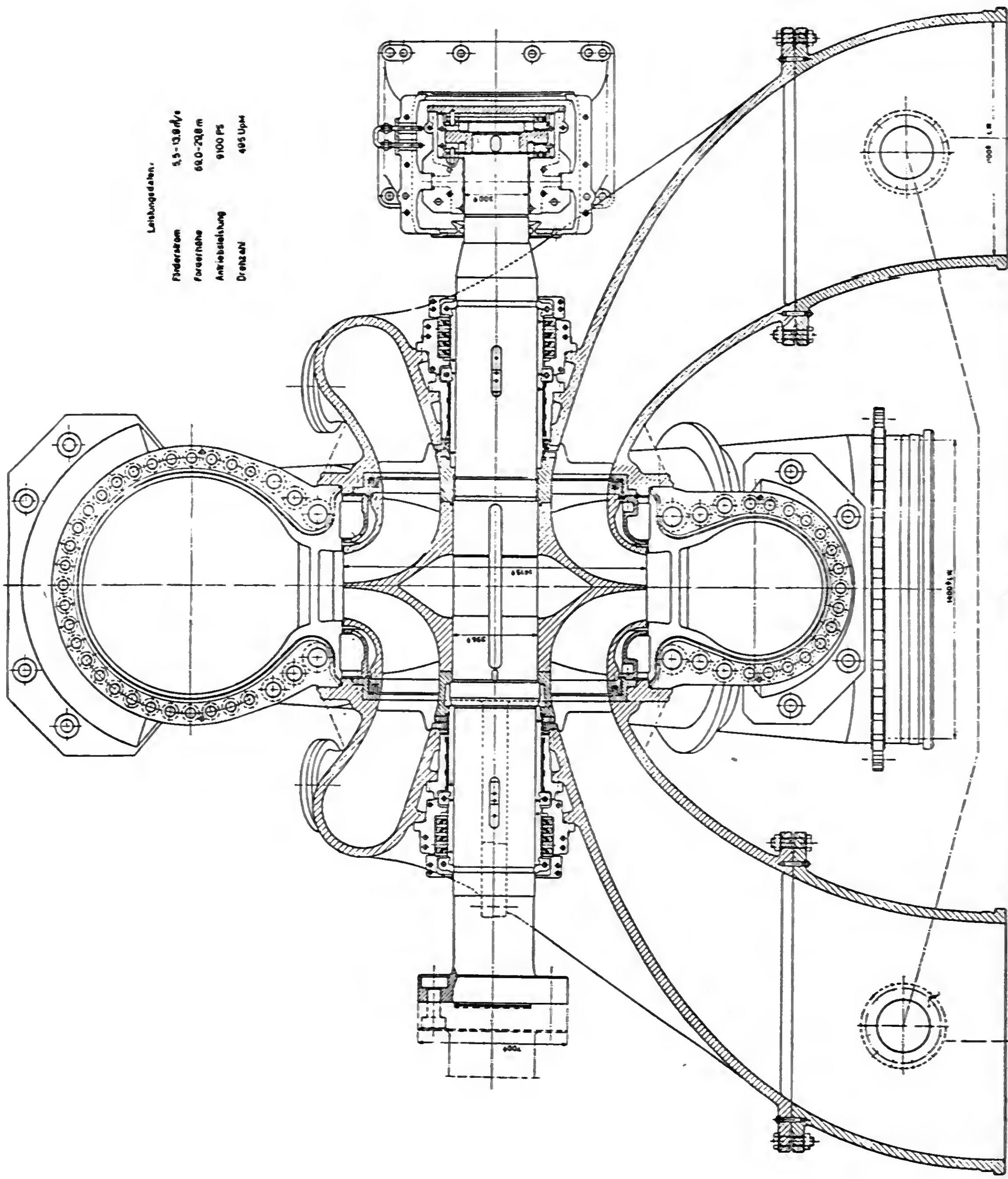


Fig. 13.4 - Section of Pump.

Fig. 13.5 (G4-13)
View of Drossen Dam

Fig. 13.6 (W5-0) Upper Storage Lake

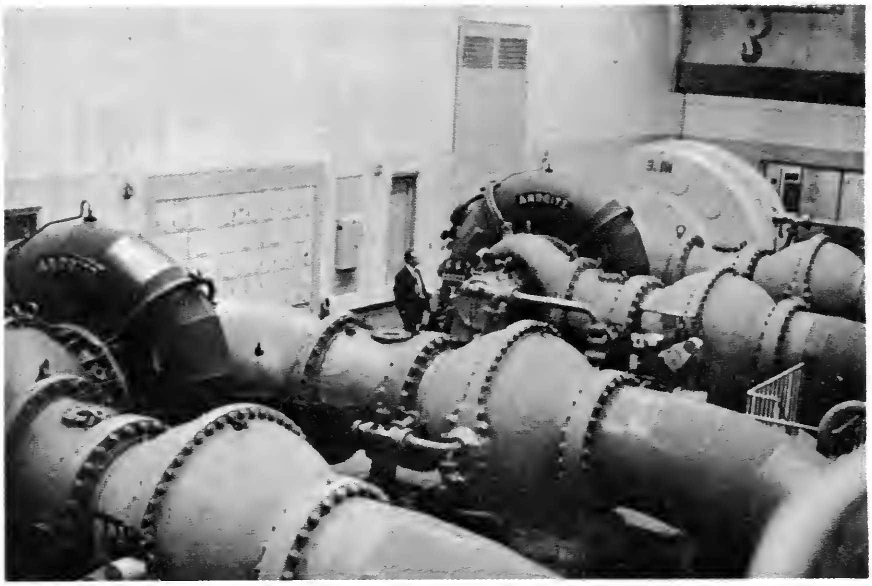



Fig. 13.7 (G4-18) Plant Interior

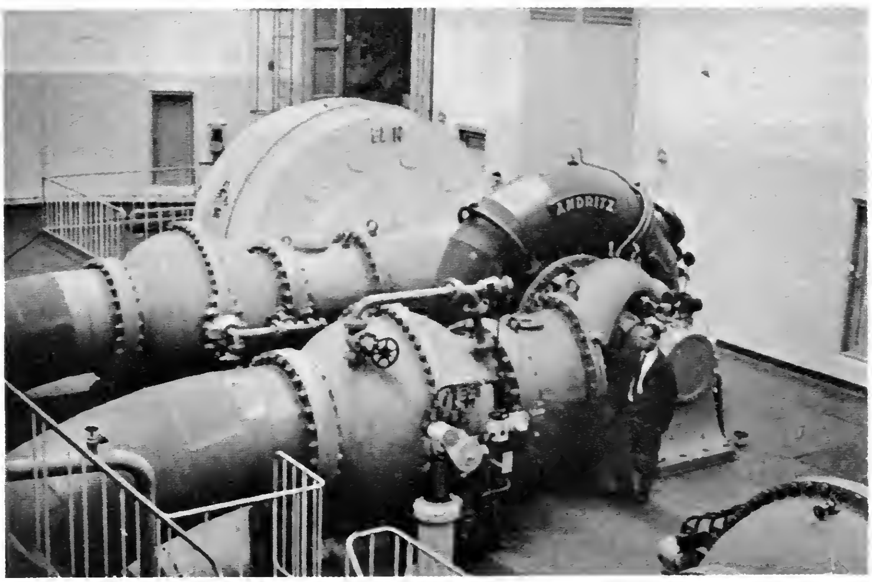



Fig. 13.8 (G4-17) Pump and Motor showing Intake Valves

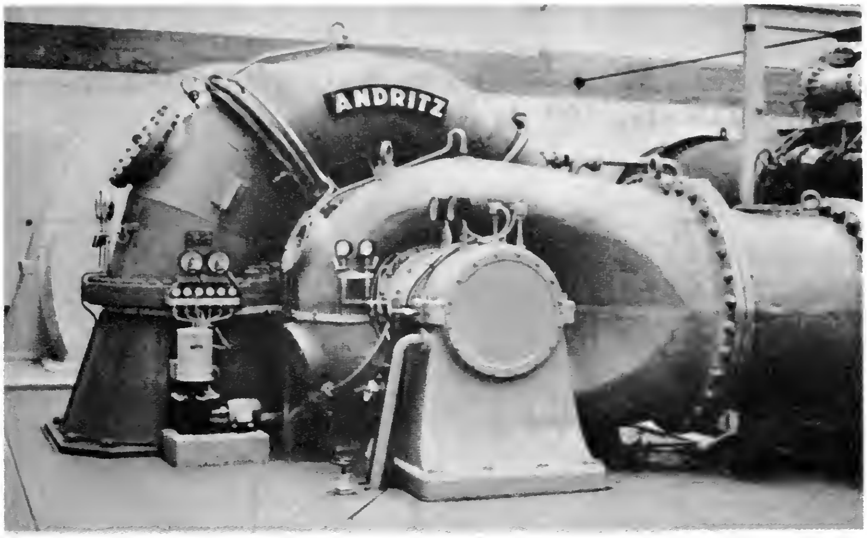



Fig. 13.9 (G4-14) View of Pump

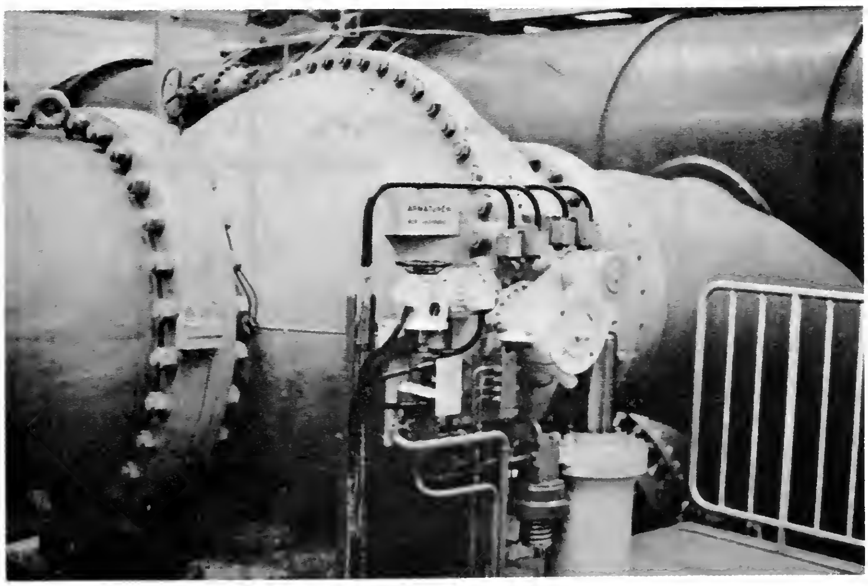


Fig. 13.10 (G4-15) Intake Valve

## Vibration Records

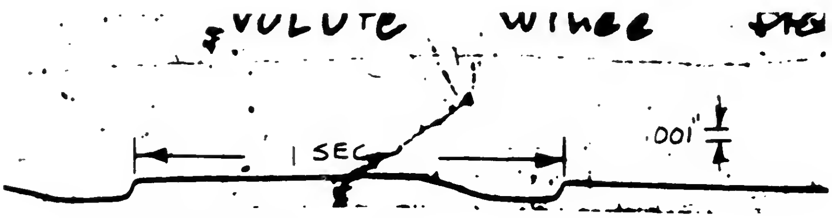
Tauernkraftwerke AG, Salzburg, Austria

Plant : Möll (underground power house)

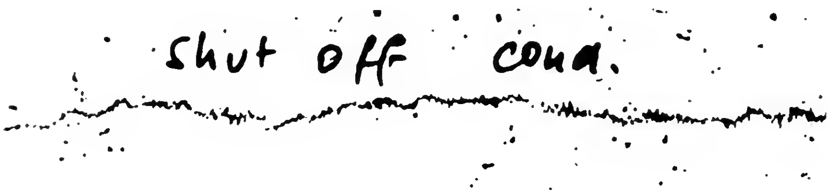
Units : two, single-stage, double flow, horizontal pumps; 8000 HP, 318 cfs, 197 ft, 495 RPM

Records-taken : July 14, 1964

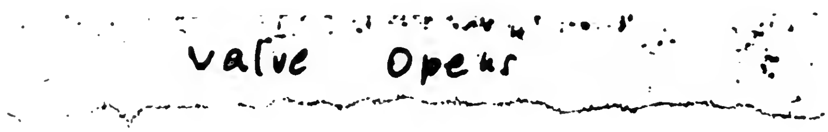
Unit 1




1. Volute while starting




2. Volute, discharge valve closed




3. Volute, discharge valve opening

| Record | Frequency c.p.m. | Average Amplitude inches |
|---|---|---|
| 1. Volute while starting | ---- | less than .0002 |
| 2. Volute, discharge valve closed | 12,000 | .0007 |
| 3. Volute, discharge valve opening | 9600 | .0004 |

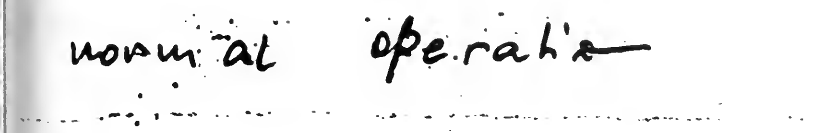
Figure 13-11

## Vibration Records (cont.)

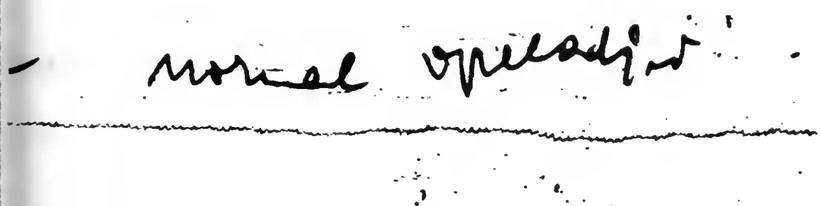
Tauernkraftwerke AG, Salzburg, Austria

Plant : Möll (underground power house)

Unit 1 (cont.)

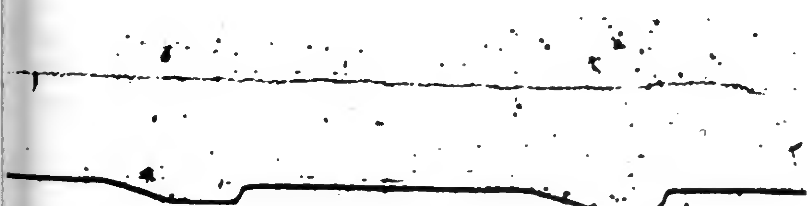



4. Bearing, normal pump operation




5. Volute, normal pump operation

6. Suction casing, normal pump operation



7. Bearing, normal pump operation

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| ---- | less than .0002 |
| 12,000<br>3600 | .0008<br>.0003 |
| ---- | less than .0002 |
| 8400 | .0002 |

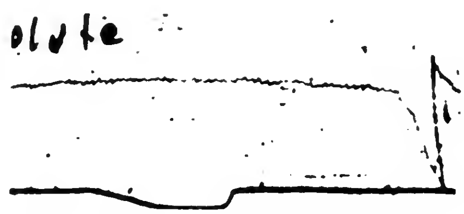
Figure 13-12

## Vibration Records (cont.)

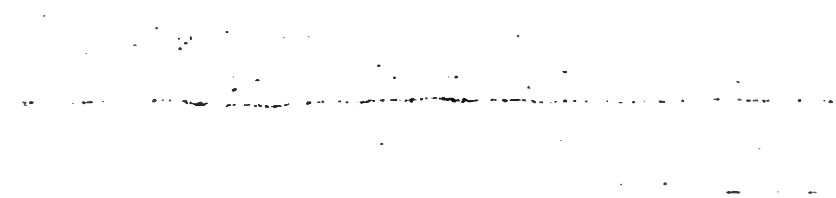
Tauernkraftwerke AG, Salzburg, Austria

Plant : Mölll (underground power house)

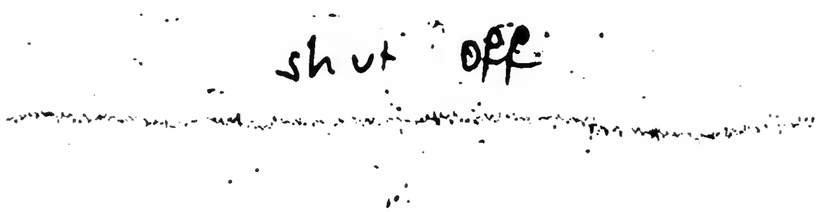
Unit 1 (cont.)



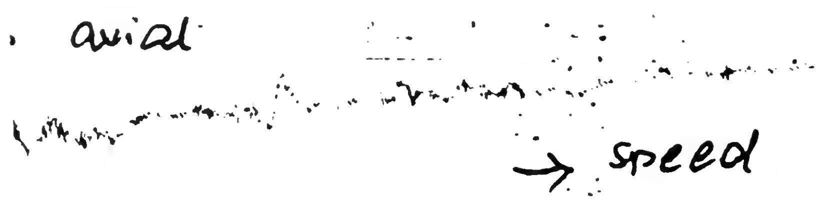

8. Volute, normal pump operation



9. Volute, discharge valve closing




10. Volute, discharge valve closed




11. Bearing (longitudinal), discharge valve closed and speed slowing down

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 9600 | .0003 |
| 7200 | less than .0002 |
| 9000 | .0008 |
| 12,000 to ---- | .0020 to less than .0002 |

Figure 13-13

PLANT NAME: GRIMSEL

REPORT NO.: 14

| | |
|---|---|
| LOCATION-ALTITUDE: | Near Grimsel Pass, Switzerland - 5800' |
| OWNER: | Kraftwerke Oberhasli A.G. |
| ADDRESS: | Innertkirchen, Switzerland |
| TYPE OF PLANT: | Underground |
| SERVICE | Pump Storage |
| TYPE OF WATER: | Glaciel Melt - Sometimes milky |
| UNITS INSTALLED: | One (1) Vertical - 2-Stage - Double Suction |
| HORSEPOWER: | 25,000 (1000 RPM) |
| CFS: | 141 |
| STATIC HEAD: | 1160' to 1585' |
| PLANT STARTED: | June 1954 |
| VISITED BY: | Gartmann-Hartmann-Westman<br>(Troost - July 17, 1963) |
| DATE: | July 20, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Jacob Lienhard, Asst. Wks. Mgr.<br>Herr Jenzer, Chief Operator |

REMARKS: Plant pumps water from Grimsel Lake, 6260'-5975', to Oberaar Lake at 7550'-7000'. Station 177' x 69' x 43'. Plant also contains two Pelton type turbines with one generating in between. Takes water from Oberaar Lake and discharges into Räterishboden Lake at 5800' (1640' head).

PUMPS:

| | |
|---|---|
| TYPE: | Vertical - 2-stage - Double Suction |
| MANUFACTURER: | Sulzer (Winterthur) |
| SIZE DISCHARGE: | 27.6" (700 mm) |
| SIZE SUCTION: | 2 x 23.6" (600 mm) |
| RPM: | 1000 |
| CFS: | 141 |
| HEAD: | 1312 |
| H.P. REQUIRED: | 24,000 |
| N s.: | 1375 |
| INSTALLED: | June 1954 |
| HRS. OF OPERATION | 21,000 |
| MIN. SUBMERGENCE: | 230 (Rarely) |
| NORMAL SUBMERGENCE: | 328' |
| MAX. SUBMERGENCE: | 460' |
| REMARKS: | |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | Unknown |
| MODEL ACTUAL: | " |
| PROTOTYPE-GUARANTEED: | 85 |
| PROTOTYPE-ACTUAL: | 87.6 (Max. 88.2 @ 122 CFS) |
| METHOD OF TEST: | Flow Meters in Pressure Shaft (Prof. Gerber) |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 27.6" (700 mm) |
| DIAMETER IMPELLER: | 51" (1300 mm) |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 15.75" |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | 13% Cr. Steel |
| MATERIAL IMPELLER RINGS: | 13% Cr. Steel |
| MATERIAL-CASING RINGS: | C.I. (Labyrinth Type) |
| RADIAL CLEARANCE: | 1.0 mm |
| MATERIAL BALANCING RINGS: | None |
| MATERIAL INTERSTAGE SEAL: | C.I. Labyrinth - Bronze Sleeve |
| RADIAL CLEARANCE: | 0.5 mm |
| MATERIAL DIFFUSER: | 13% Cr. Steel |
| BEARING: | One (1) Babbitt lined bearing in Pump |
| THRUST BEARING: | Kingsbury type - in motor |

| | |
|---|---|
| TYPE OF PACKING: | Labyrinth |
| MATERIAL OF PACKING: | Babbitt |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | Stuffing Box operated 10 years with no trouble. Leakage increased from 24 GPM to 58 GPM (both sides) in 20,000 hrs. |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical Synchronous Solid Poles |
| MANUFACTURER: | Brown Boveri |
| H.P.: | 25,000 |
| R.P.M.: | 1000 |
| VOLTAGE: | 13,500 |
| STARTING: | Reduced voltage - 70% Transformer Tap |
| REMARKS: | Closed Valve - Starts in 13 Seconds |

TURBINE:

| | |
|---|---|
| TYPE: | None with Pump |
| MFG.: | - |
| HEAD: | - |
| R.P M.: | - |
| H.P.: | - |

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | Spherical |
| MANUFACTURER: | Von Roll |
| SIZE: | 27.6" (700 mm) |
| OPERATION: | Water Pressure |

DISCHARGE:

| | |
|---|---|
| TYPE: | Needle |
| MANUFACTURER: | Charmiles |
| SIZE: | 27.2" (700 mm) |
| OPERATION: | |
| OPENING: | Oil Hydraulic |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |

REMARKS: Needle valve backed up by Von Roll spherical valve, always open except for maintenance. Charmiles valve has bronze seats. Von Roll forged. No maintenance required in nine (9) years.

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | No Data |
| LENGTH: | " " |

| | |
|---|---|
| MATERIAL: | No Data |
| TYPE OF UPPER GATE: | Valve at Surge Tank |
| SURGE TANK: | At end of Horizontal Tunnel |

REMARKS: Penstock at sharp incline, under Grimsel Lake for approximately 4300', to elevation of 7260', then into horizontal tunnel approximately 14,800'.

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Poor - Quartz particles .1 to .001 mm - approx. 1 P. P. M. |
| Ph: | - |
| HARDNESS: | Soft |
| REMARKS: | Solids may reach 10 to 100 P. P. M. at times in the Spring. |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | June to September (3-4 Mos.) Continuous two months. |
| STARTS/DAY: | Approx. 10 per month |
| HOURS OF OPERATION: | 21,000 (2000/year) |
| UNPLANNED OUTAGES: | - |
| CAUSE: | - |
| INSPECTION SCHEDULE: | 5 years |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | 10 years |
| TIME REQUIRED: | 3 weeks - 4 men |
| IMPELLER CAVITATION: | None |

| | |
|---|---|
| SEAL RING WEAR: | 0.5 mm after 20,000 hrs. |
| NOISE LEVEL-START: | C- 105-110 |
| NOISE LEVEL-RUN: | A- 96; B- 101; C- 102 |
| VIBRATION: | - |
| REMARKS: | Pump mounted on rails and moved to one side for servicing. No repair work on impellers or diffusers, except impeller tips were welded with 13% Cr. steel.<br><br>Seal Ring clearance increased from 1 mm to 1.5 mm in 10 years. (Proposed repair consists of re-machining casing rings and installing oversized impeller rings. |

## GENERAL REMARKS

The Grimsel-Oberaar Power Station is primarily a winter station. It converts 190 million kWh of summer power into winter power and generates in addition 30 million kWh of winter electricity. It utilizes the uppermost step of the Oberaar waters, with a catchment area of 7.5 square miles, and those of Lake Trübten, with a catchment area of 0.7 square miles, making 8.2 square miles in all. The annual discharge totals 1400-1550 million cu. ft. of water.

The tributary waters of the Oberaar are collected and stored in the artificial Lake Oberaar, with a capacity of 2050 million cu. ft. As the natural inflow is only 1350 million cu. ft., the other 700 million cu. ft. is taken in summer from Lake Grimsel, and is pumped into Lake Oberaar by a Sulzer storage pump with a delivery head of 1312-1475 ft. The waters of Lake Oberaar are then utilized for the generation of winter power in the Grimsel, Handeck II and Innertkirchen stations with a total gross head of about 5500 ft.

A remarkable feature is the change in the production of the Oberhasli stations resulting from the construction of the Grimsel-Oberaar plant. Before this station was built, 57% of the total power was generated in summer and only 43% in winter. Today the situation has been reversed: 37% is produced in summer and 63% in winter.

Fig. 2 is a diagram of pump and turbine operation in the Oberaar plant. It shows that Lake Grimsel (2), from which the water required for pumped storage is taken, is situated at a higher altitude than the pump, while the turbines utilize the full head from Lake Oberaar (1) to Räterichsboden Reservoir (3). This unusual arrangement was extremely advantageous for the pump, as the available positive suction head of about 174 to 466 ft. permitted the use of a double-flow unit running at the high speed of 1000 revs. per min. A single-flow unit was not indicated, as at this high speed the first stage would have reached the capacity limit even if the design had been chosen to minimize cavitation.

The station takes the form of a chamber 177 ft. long, 69 ft. broad and 43 ft. high situated deep in the rock. Both the storage pumping set and the turbine-alternator are installed here. The latter consists of a horizontal alternator of 45,000 kVA and two single-nozzle Pelton turbines, of 20,750 H.P. each, placed on either side of it. The flow to each turbine is 129 cu. ft. per sec., the speed of rotation 375 revs. per min. Space has been left in the hall for the later installation of a vertical turbine-alternator set which would be connected to the inlet pipe of the pump and would utilize the head between Lake Grimsel and Räterichsboden Reservoir.

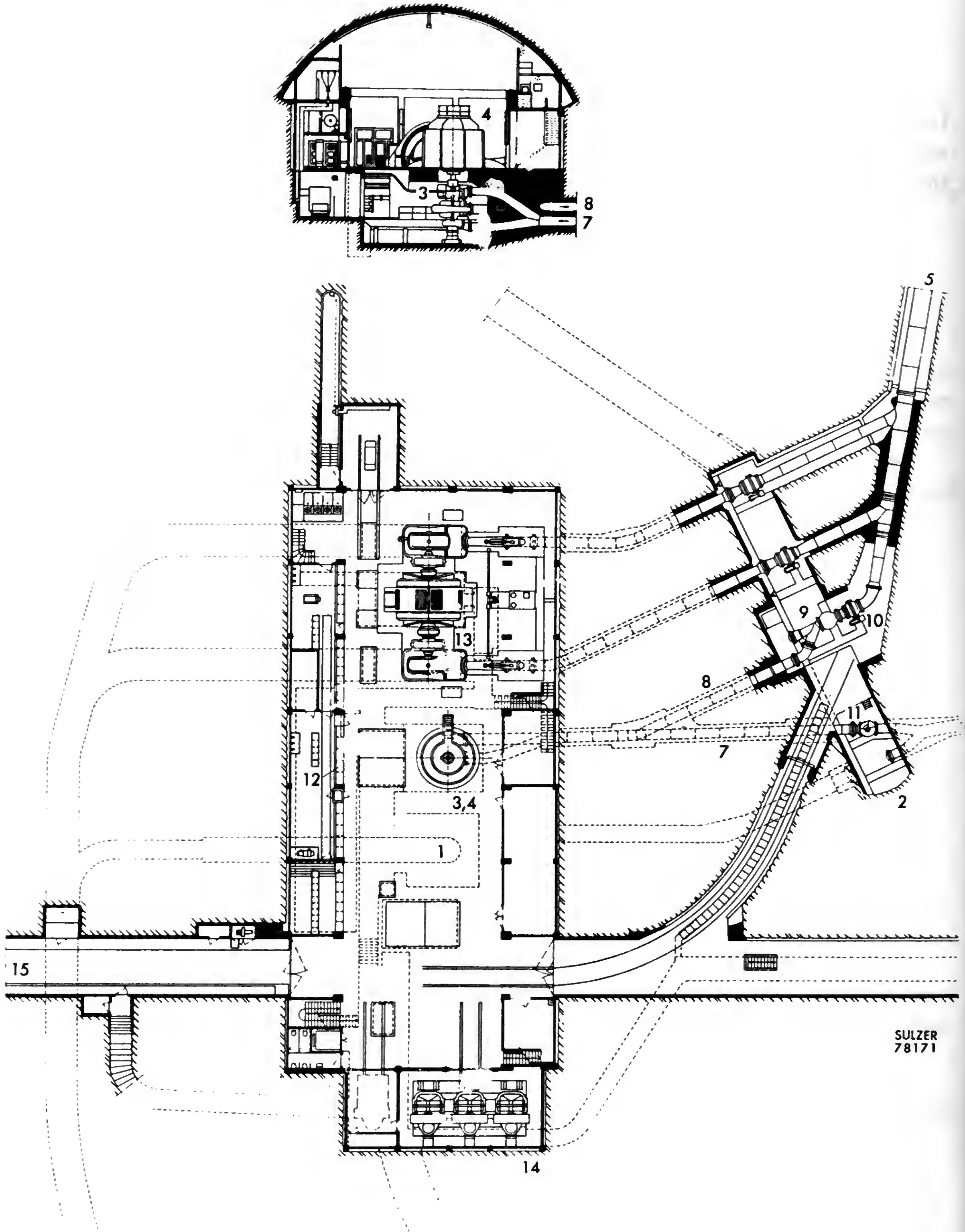
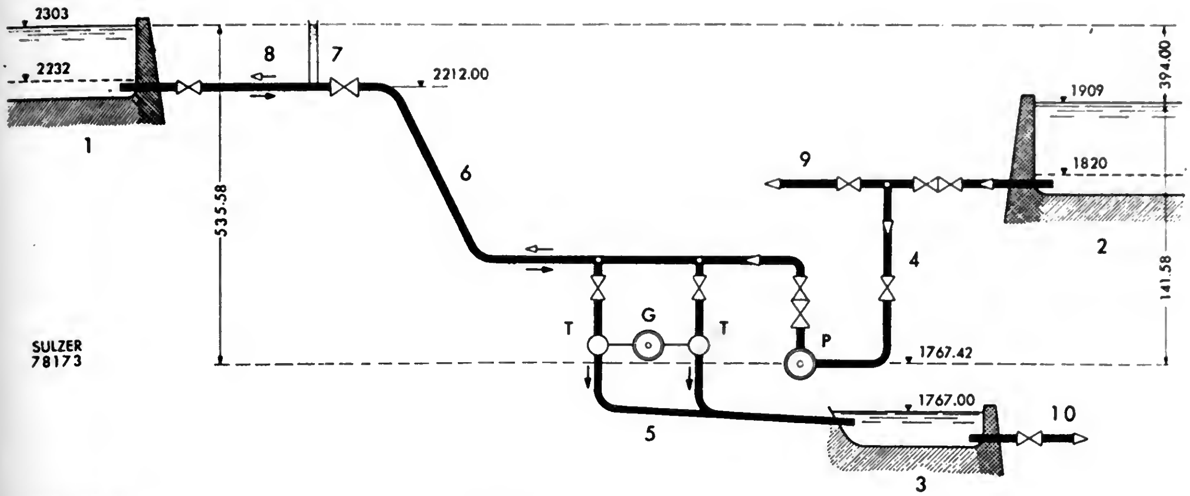



Fig. 14.1 - Plan and Section of Grimsel Station




1 Lake Oberaar
2 Lake Grimsel
3 Räterichsboden Reservoir
4 Feed pipe to pump
5 Grimsel Power Station
6 Pressure shaft
7 Surge tank
8 Supply tunnel
9 Pipe to Lake Gelmer
10 Pipe to Handeck Station II

T Turbine
G Generator
P Sulzer storage pump
◁— Pump operation
—▶ Turbine operation

Fig. 14.2 - Schematic Diagram of Oberaar Development

In the foreground, the Brown Boveri vertical motor rated at 28,600 H.P., 1,000 r.p.m., which drives the Sulzer storage pump. In the background, the Escher Wyss double Pelton turbine set of 41,500 H.P., 375 r.p.m., with three-phase alternator of 45,000 kVA supplied by the Ateliers de Construction Oerlikon.

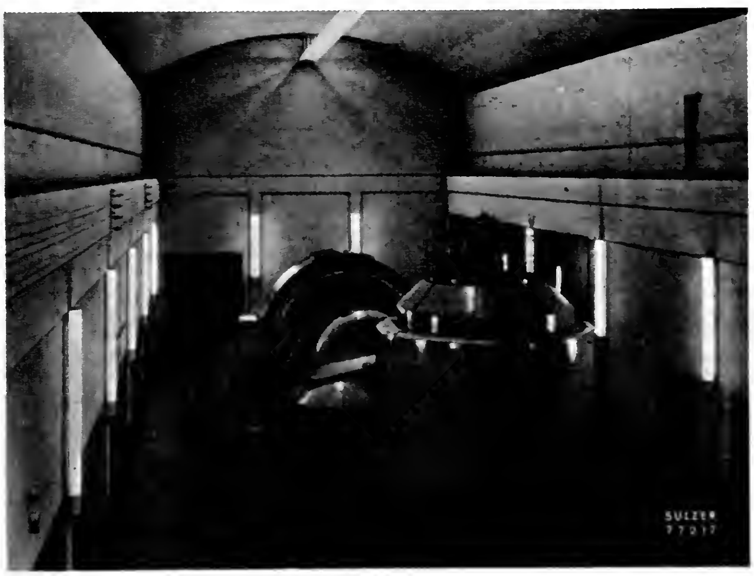


Fig. 14.3 - View of Plant Interior

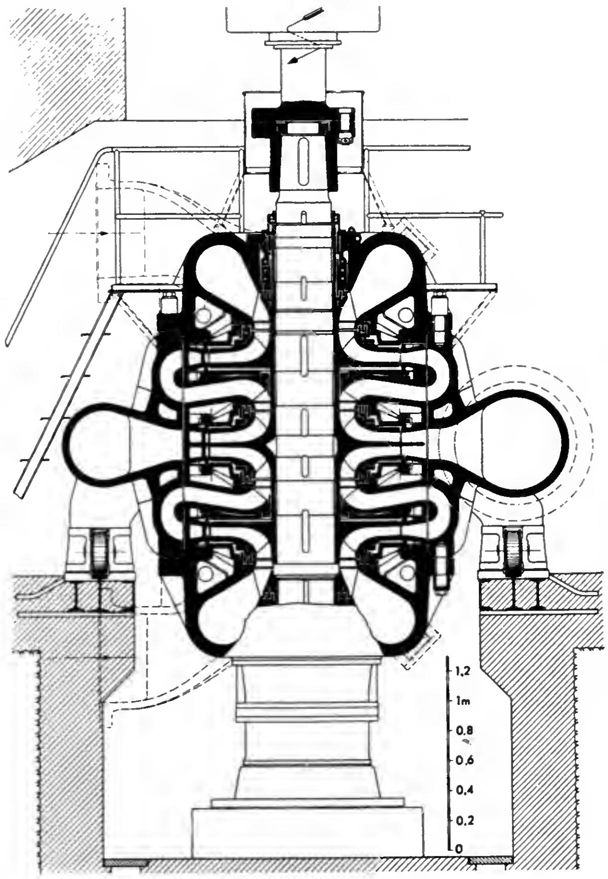



Fig. 14.4 - Section of Sulzer Pump in Grimsel Station

Fig. 14.5 - Pelton Turbine (left) and Motor (right)

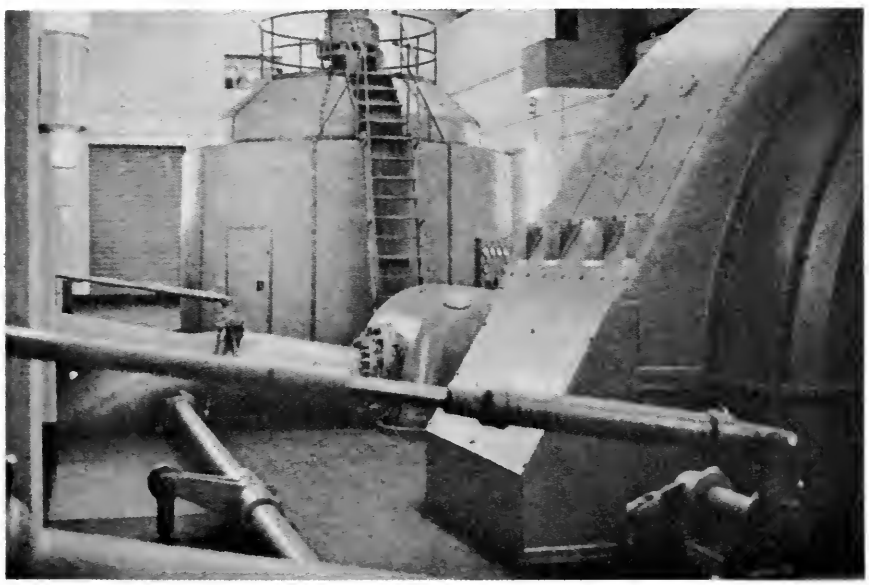


Fig. 14.6 - Pelton Turbine Unit (right) and Motor (left)

Fig. 14.7 - Oberaar Storage Lake

Fig. 14.8 - Terrain above Oberaar Lake

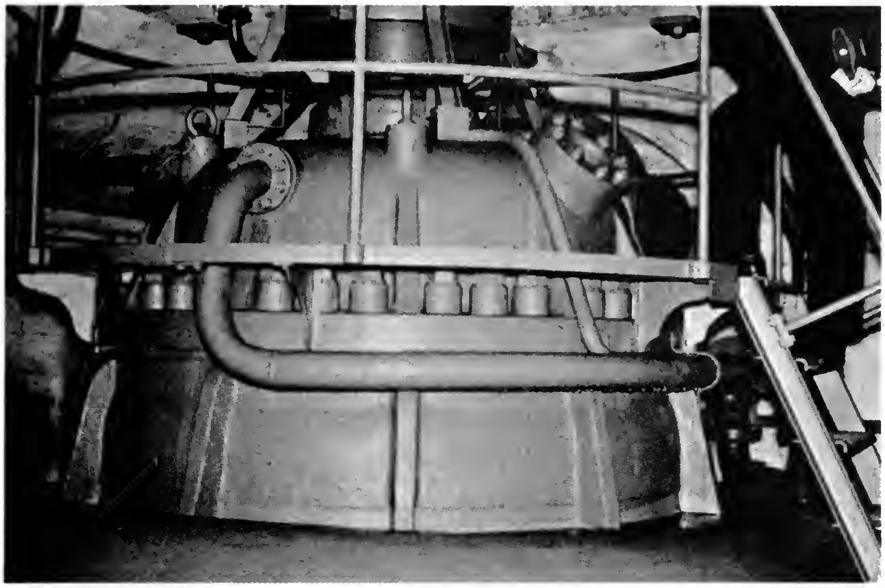


Fig. 14.9 - Pump upper half

Fig. 14.10 - Vertical, 2-stage, double-flow pump

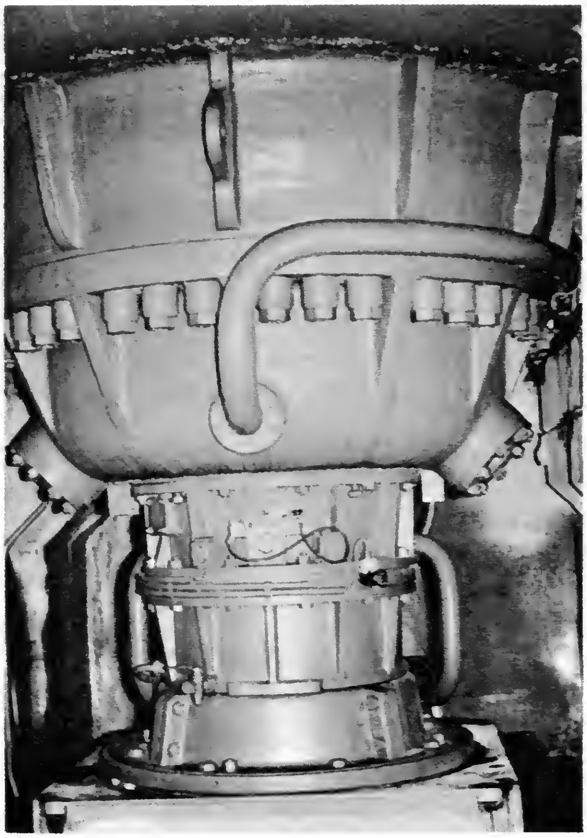


Fig. 14.11 - Pump base

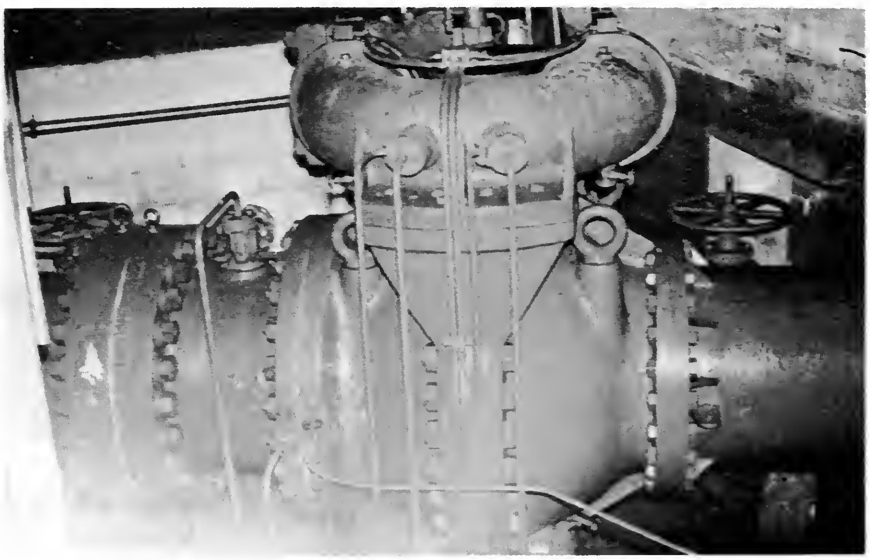


Fig. 14.12 - Spherical Valve, Pump Inlet

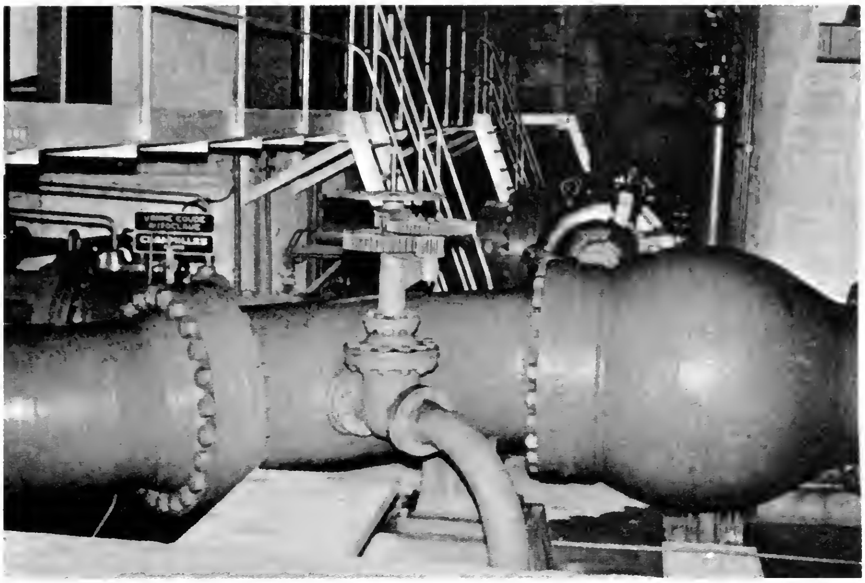


Fig. 14.13 - Needle Valve, Pump Discharge

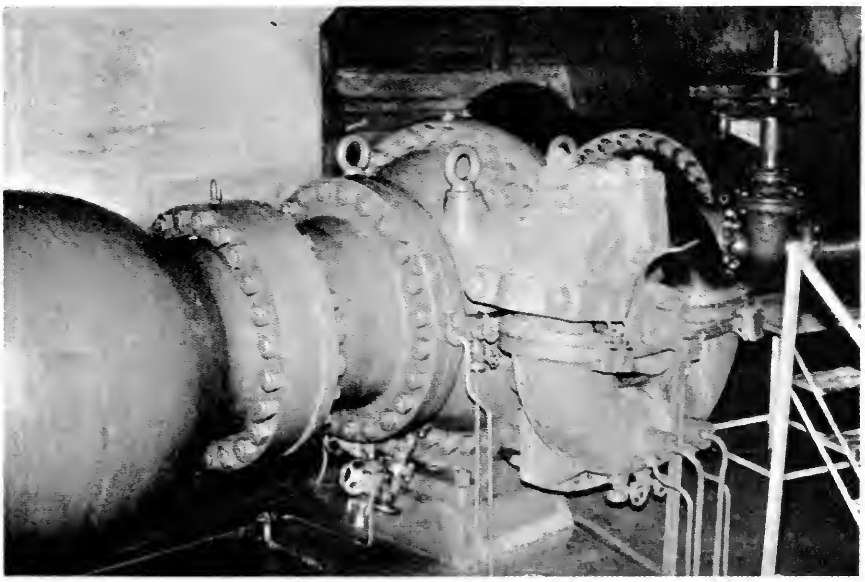


Fig. 14.14 - Back-up Spherical Valve, Pump Discharge

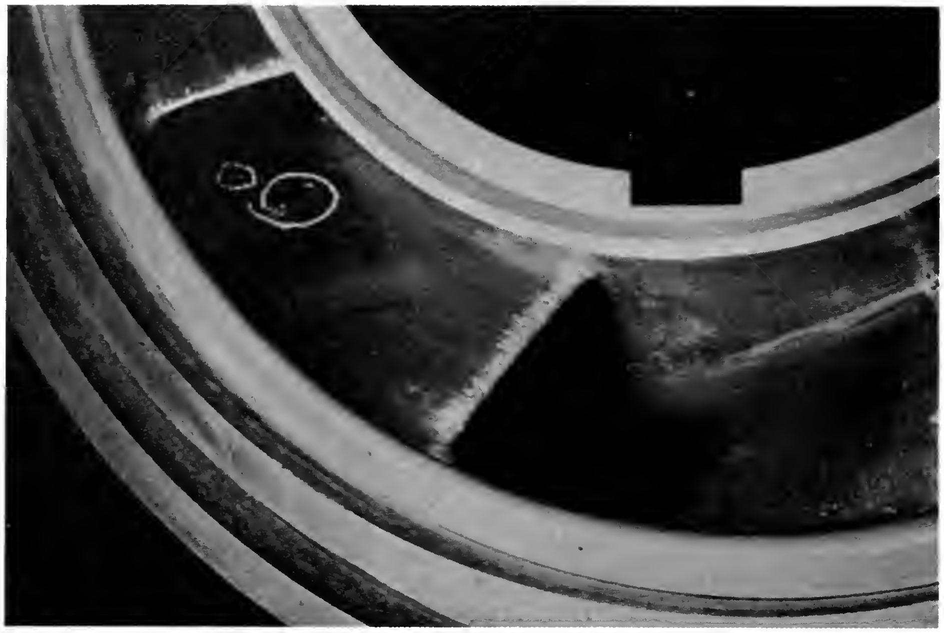


Fig. 14.15- Grimsel-Oberaar Storage Pump Impeller inlet showing wear from sand and small inclusions.

Fig. 14.15a Grimsel-Oberaar Storage Pump Guide Vane Inlet showing wear from sand and small inclusions.

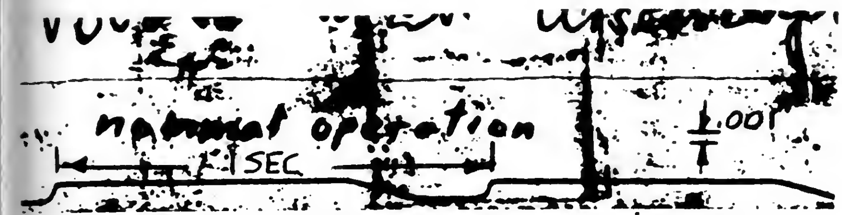
## Vibration Records

Kraftwerke Oberhasli AG, Innertkirchen, Switzerland

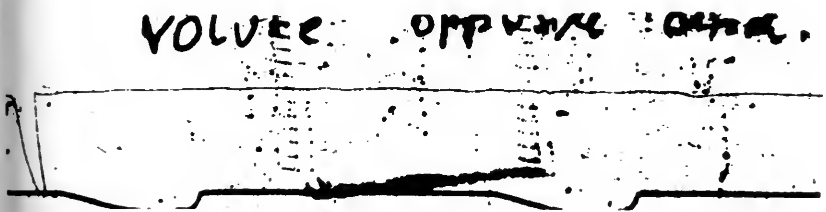
Plant : Grimsel - Oberaar (underground power house)

Single Unit : 2-stage, double flow, vertical pump;
25,000 HP, 141 cfs, 1310 ft, 1000 RPM

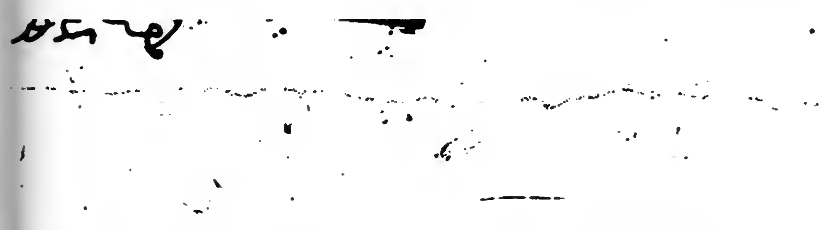
Records-taken : July 21, 1964



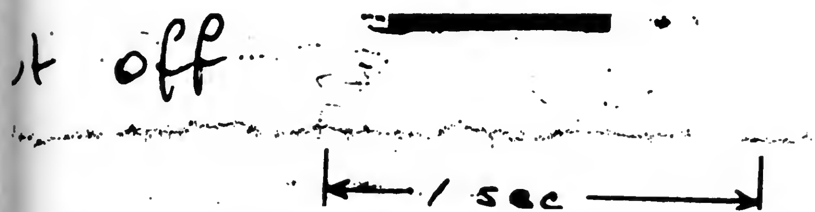

1. Volute near discharge - normal operation



2. Volute opposite discharge - normal operation



3. Volute opposite discharge - discharge valve closing




4. Volute opposite discharge - discharge valve closed

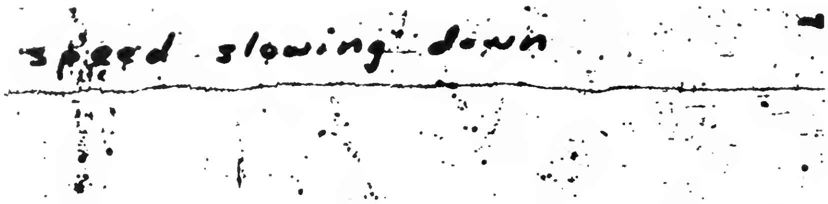
| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| ---- | less than .0002 |
| ---- | less than .0002 |
| 9000 | .0004 |
| 9000 | .0008 |

Figure 14.16

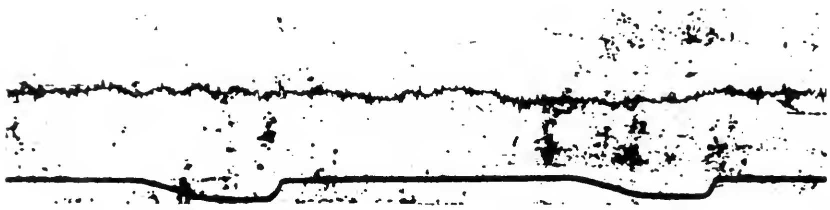
## Vibration Records (cont.)

Kraftwerke Oberhasli AG, Innertkirchen, Switzerland

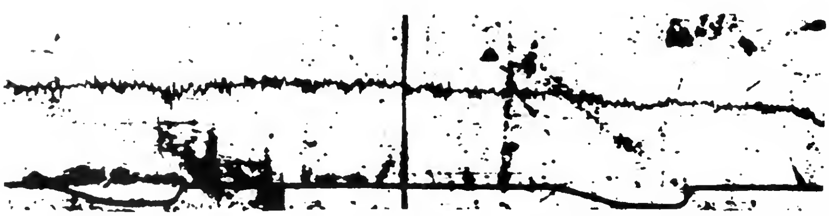
Plant : Grimsel - Oberaar (underground power house)




5. Volute opposite discharge - motor off, speed slowing down



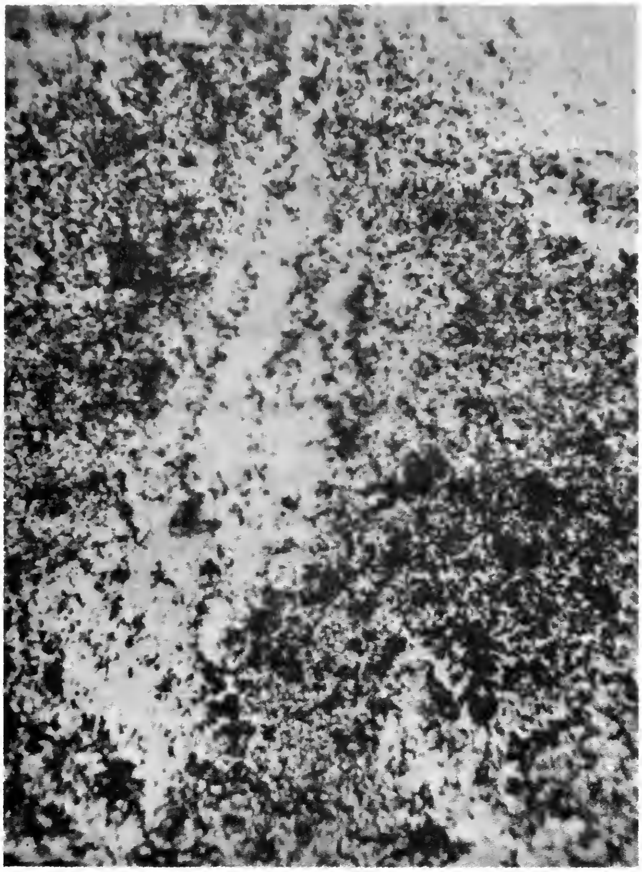
6. Volute opposite discharge - motor started, discharge valve closed



7. Volute opposite discharge - discharge valve closed

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 9000 to 6000 | .0006 to less than .0002 |
| 9000 | .0008 |
| 9000 | .0008 |

Figure 14.17



Grimsel 70X

Fig. 14.18 - Microphotograph of Silt.

Microscopic analysis of this silt indicated the same general appearance of the Stafel silt except that the particles were very much smaller. The majority of crystals were in the particle size range of 10 to 25 microns. They were slightly harder than glass, insoluble in mineral acids, and would not be expected to be strongly abrasive to softer materials. Their fineness would, however, permit penetration into small interstices, such as bearing surfaces in machine parts, and abrasion could then result.

PLANT NAME: Z'MUTT

REPORT NO.: 15

| | | | |
|---|---|---|---|
| LOCATION-ALTITUDE: | Near Zermutt, Switzerland - 6240' | | |
| OWNER: | Grande Dixence, SA. | | |
| ADDRESS: | Lausanne, Switzerland | | |
| TYPE OF PLANT: | Underground - Pump Storage - Generating | | |
| SERVICE | Storing Water - Power Generating Units I & II - Pumps: Units III-IV - Pump Turbines. | | |
| TYPE OF WATER: | Should be clean for pumps. Not so clean for turbines. | | |
| UNITS INSTALLED: | Four vertical, two-stage, double-suction pumps (Two reversible pump turbines) | | |
| | I & II | III & IV | |
| HORSEPOWER: | 2 x 37,300 | 2 x 17,000 | (1500 RPM) |
| CFS: | 2 x 194 | 2 x 113 | |
| STATIC HEAD: | 1541' | 1200' | |
| PLANT STARTED: | Will be started in June 1965 | | |
| VISITED BY: | Gartmann - Hartmann - Westman | | |
| DATE: | July 22, 1964 | | |
| PERSON(S) INTERVIEWED & TITLE(S): | Pierre Meystre, Chief Engineer<br>Herr Perreten, Plant Chief | | |
| REMARKS: | - | | |

## PUMPS:

| | | |
|---|---|---|
| TYPE: | Two-stage, Vertical, Double-suction | |
| MANUFACTURER: | Sulzer (Winterthur) | |
| SIZE DISCHARGE: | I & II - 31.5"; III & IV - 27.6" | |
| SIZE SUCTION: | I & II - 2 x 29.5"; III & IV - 2 x 23.6" | |
| RPM: | 1500 | |
| CFS: | 194 | 113 |
| HEAD: | 1541' | 1200' |
| H.P. REQUIRED: | 37, 200 | 17, 000 |
| N s.: | 2140 | 1980 |
| INSTALLED: | To be installed in June 1965. | |
| HRS. OF OPERATION | None | |
| MIN. SUBMERGENCE: | 98.5' | 525' |
| NORMAL SUBMERGENCE: | 197' | - |
| MAX. SUBMERGENCE: | 230' | 535' |
| REMARKS: | - | |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | - |
| PROTOTYPE-GUARANTEED: | 90.3 - 91.1; 90.0 - 90.5 |
| PROTOTYPE-ACTUAL: | - |
| METHOD OF TEST: | - |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 31.5" 27.6" |
| DIAMETER IMPELLER: | 1st Stage 36.2"<br>2nd Stage 37.5" |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 11.8" |
| MATERIAL CASING: | - |
| MATERIAL IMPELLER: | - |
| MATERIAL IMPELLER RINGS: | - |
| MATERIAL-CASING RINGS: | - |
| RADIAL CLEARANCE: | - |
| MATERIAL BALANCING RINGS: | - |
| MATERIAL INTERSTAGE SEAL: | - |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | - |
| BEARING: | - |
| THRUST BEARING: | - |

| | |
|---|---|
| TYPE OF PACKING: | - |
| MATERIAL OF PACKING: | - |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | | |
|---|---|---|
| TYPE: | Vertical - Synchronous | |
| MANUFACTURER: | Orlikon - Sécheron | |
| H. P.: | 40,000 | 18.000 |
| R. P. M.: | 1500 | |
| VOLTAGE: | - | |
| STARTING: | Presumably direct with reduced voltage. | |
| REMARKS: | Believe motors have solid poles. (No amortisseur windings) | |

TURBINE:

| | |
|---|---|
| TYPE: | Pump - Francis |
| MFG.: | Sulzer |
| HEAD: | 1510' |
| R. P. M.: | 1500 |
| H. P.: | 21,400 |
| REMARKS: | - |

VALVES:

INTAKE:

| | | |
|---|---|---|
| TYPE: | Butterfly | |
| MANUFACTURER: | - | |
| SIZE: | 2 x 47.2" | 1 x 55" (also 1 x 39.4") |
| OPERATION: | - | |

DISCHARGE:

| | | |
|---|---|---|
| TYPE: | Spherical | |
| MANUFACTURER: | - | |
| SIZE: | 31.5' | 27.6' |
| OPERATION: | | |
| OPENING: | - | |
| CLOSING: | - | |
| TIME OF CLOSING: | | |
| NORMAL: | - | |
| EMERGENCY: | - | |
| REMARKS: | - | |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | - |

## GENERAL REMARKS

Two pumps will take water from Z'Mutt collector at 6460' (maximum) and deliver it to the main collecting tunnel of Grande Dixence at approximately 7930'.

The other two take water from a collector at 6780' and raise it to the same collector. These two can also operate as turbines, taking water from the 7930' level and discharging into the Z'Mutt collector at 6460'.

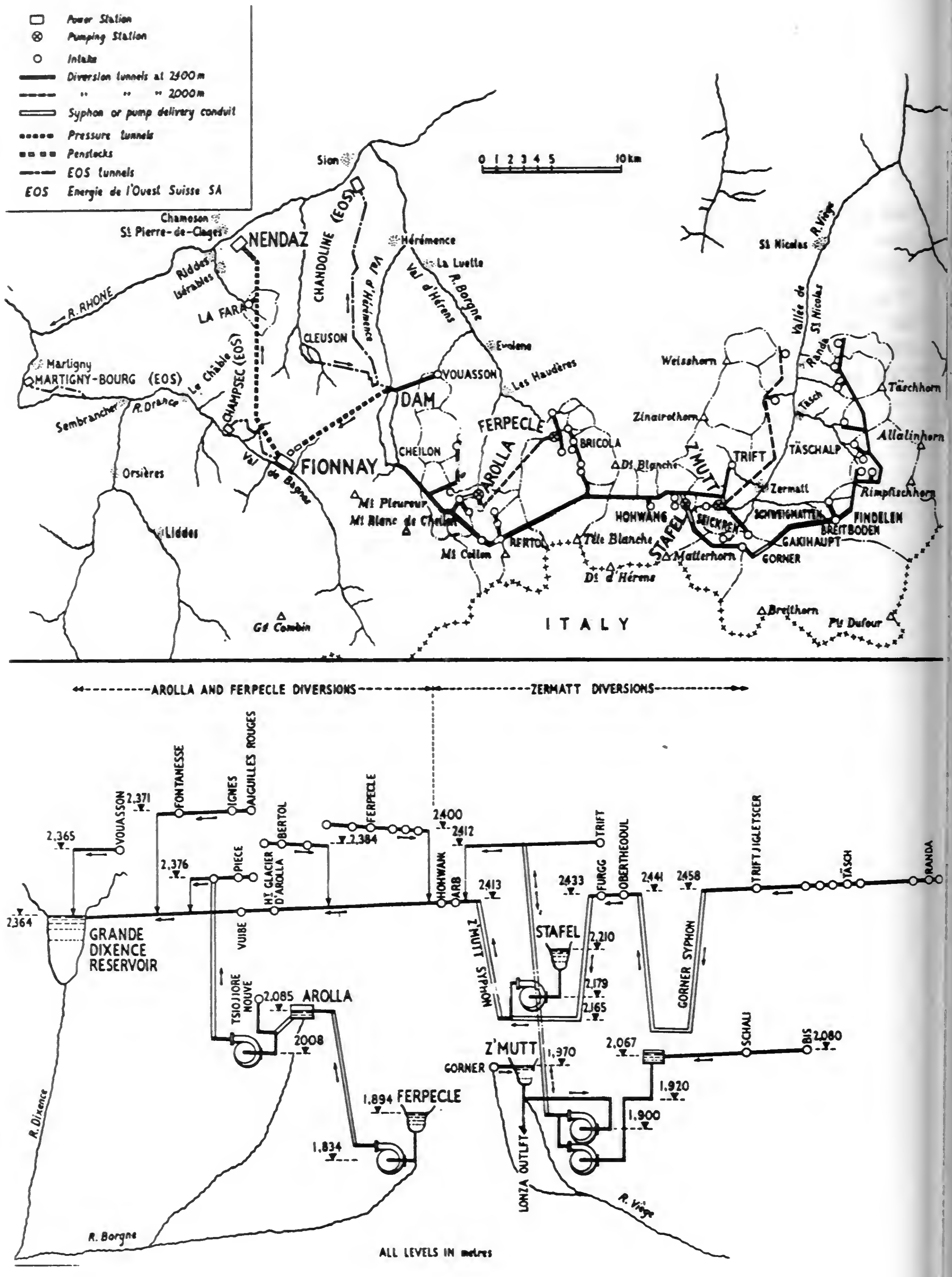
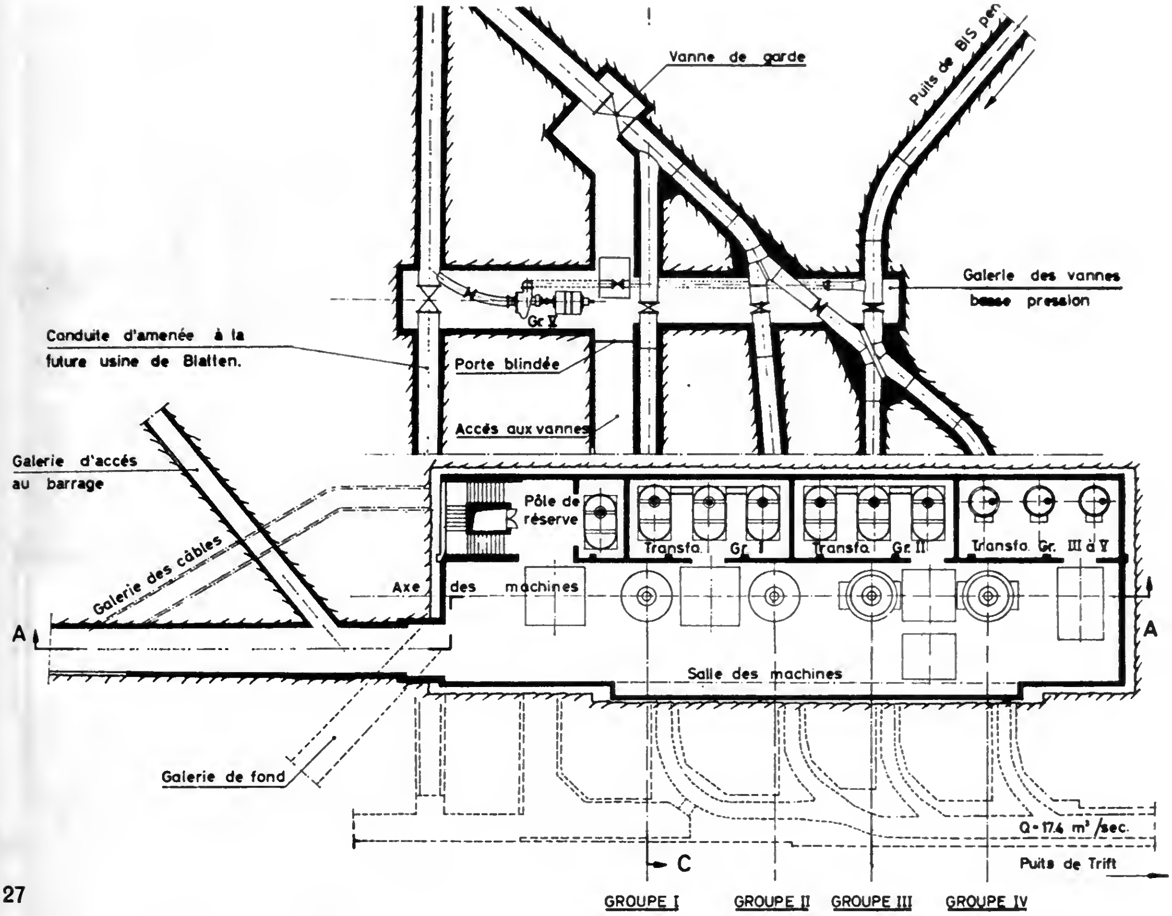
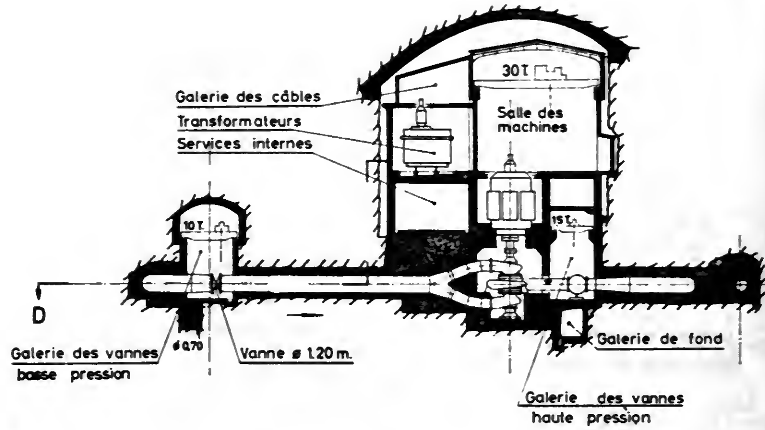



Fig. 15-1 - Schematic Diagram of Grande Dixence System




27

Fig. 15-2 - Plan of Z'Mutt Station




28

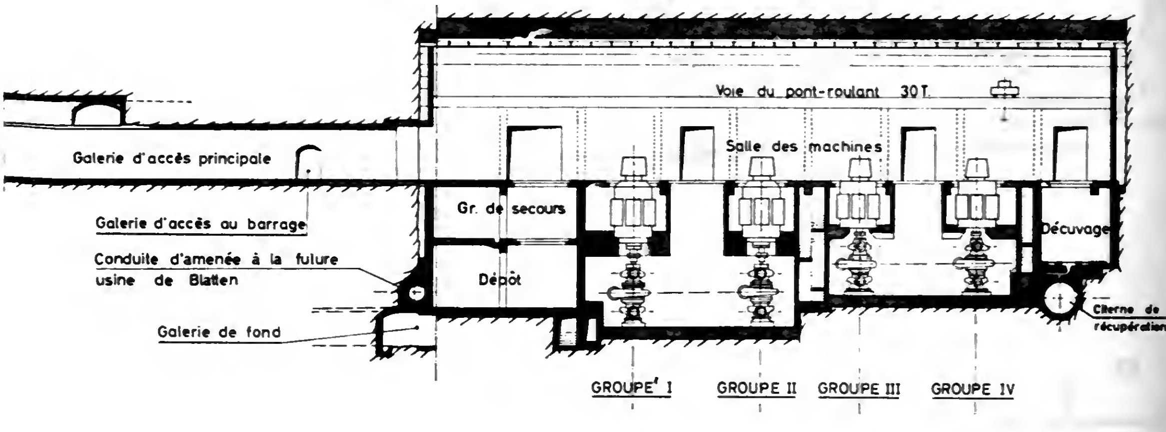



Fig. 15-3 - Sections of Z'Mutt Station

Fig. 15.4 (G5-11)
Pump being installed

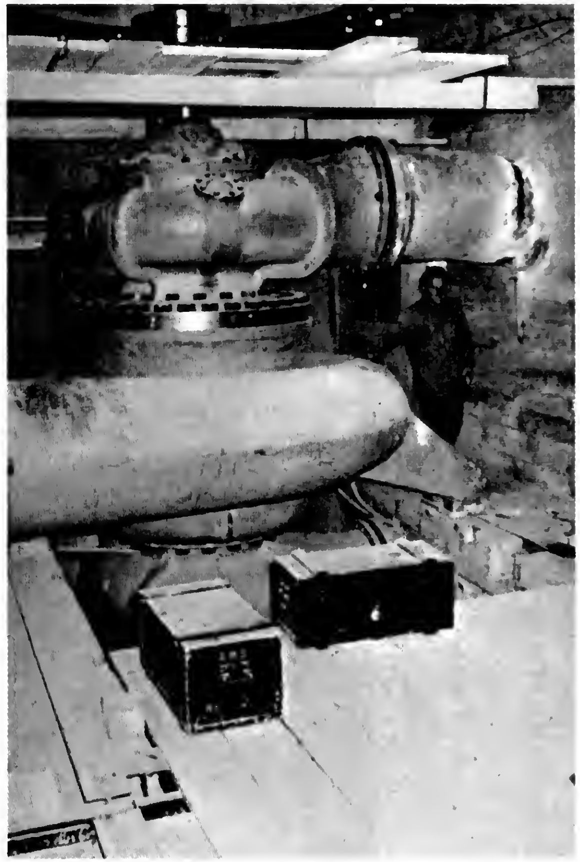


Fig. 15.5 (W7-37)
Pump being installed

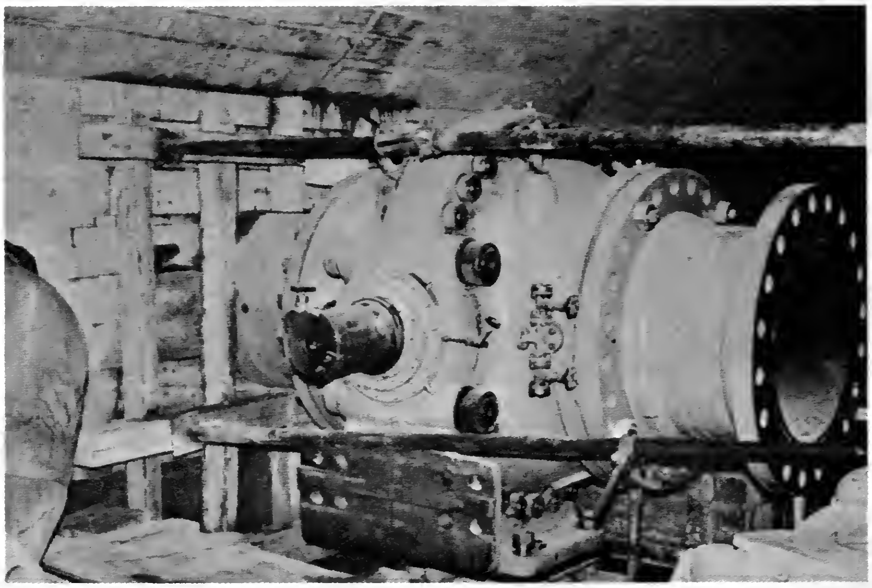


Fig. 15.6 (G5-15) Valve in Process of Installation

PLANT NAME: STAFEL

REPORT NO.: 16

| | |
|---|---|
| LOCATION-ALTITUDE: | Stafel, Switzerland - 7160' (at base of the Matterhorn) |
| OWNER: | Grande Dixence, S. A. |
| ADDRESS: | Lausanne, Switzerland |
| TYPE OF PLANT: | Surface - Pump Storage (only) |
| SERVICE | Power for Network - Summer operation as pump. |
| TYPE OF WATER: | Glacier melt - Sandy |
| UNITS INSTALLED: | Three horizontal single-stage, double-flow |
| HORSEPOWER: | 3 x (10,550 to 10,650) - 1500 RPM |
| CFS: | 3 x (113 to 119) |
| STATIC HEAD: | 715-682 |
| PLANT STARTED: | May 1961 |
| VISITED BY: | Gartmann-Hartmann-Westman |
| DATE: | July 22, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Pierre Meystre, Chief Engineer Soc. Gen. Pour L'Industrie (Formerly Chief Engineer of Grande Dixence) |
| REMARKS: | A pumping station only. Collects water from Z'Mutt Glacier at 2200 meters elevation, and delivers it to the main collector for the Grande Dixence Reservoir at approx. 2419 meters. |

PUMPS:

| | |
|---|---|
| TYPE: | Horizontal - Single-Stage - Double Suction Pump |
| MANUFACTURER: | Sulzer (Winterthur) |
| SIZE DISCHARGE: | 27.5" (700 mm) |
| SIZE SUCTION: | 2 x 21.6" |
| RPM: | 1500 |
| CFS: | 113 - 119 |
| HEAD: | 715 - 682 |
| H.P. REQUIRED: | 10,200 10,300 |
| N s.: | 1730 1840 |
| INSTALLED: | May 1961 |
| HRS. OF OPERATION | I - 3093; II - 4700; III - 5772 |

| | |
|---|---|
| MIN. SUBMERGENCE: | 69' |
| NORMAL SUBMERGENCE: | 72' |
| MAX. SUBMERGENCE: | 85' |
| REMARKS: | Starts in June - - 1 or 2 hrs./day - later 24 hrs/day. Average two starts per day from middle of June or July to middle of August or September.<br>In Winter, 2 or 3 times per week (one pump only). |

EFFICIENCIES:

| | | | |
|---|---|---|---|
| MODEL GUARANTEE: | 89.3 | | |
| MODEL ACTUAL: | 89.0 | 89.3 | |
| PROTOTYPE-GUARANTEED: | 89.9 | 90.1 | 90 |
| PROTOTYPE-ACTUAL: | | 90.6 | |
| METHOD OF TEST: | - | | |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 27.5" (700 mm) |
| DIAMETER IMPELLER: | 34" |
| DIAMETER EYE: | 20" |
| DIAMETER SHAFT: | 9" (Hub 11.8') |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | 13% Chrome |
| MATERIAL IMPELLER RINGS: | Aluminum Bronze (with Grooves) |
| MATERIAL-CASING RINGS: | Cast Steel |
| RADIAL CLEARANCE: | 0.7 mm |
| MATERIAL BALANCING RINGS: | None |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | - |
| BEARING: | 7.1" x 7.1" |
| THRUST BEARING: | Double Kingsbury type - outboard of pump |

| | |
|---|---|
| TYPE OF PACKING: | Labyrinth |
| MATERIAL OF PACKING: | Babbitt lined bronze - with grooves |
| MATERIAL OF SLEEVE: | Stainless steel |
| CLEARANCE: | 0. 4 mm |
| REMARKS: | No repairs or replacement required as yet. |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Horizontal synchronous.solid poles with direct connecting exciter.95% PF |
| MANUFACTURER: | Brown Boveri |
| H.P.: | 8840 KW (11, 800 HP $\pm$ ) |
| R.P.M.: | 1500 |
| VOLTAGE: | 5000 |
| STARTING: | Against closed valve |
| REMARKS: | Directly with 5 kv - comes up to speed in 3 seconds |

TURBINE:

| | |
|---|---|
| TYPE: | Reversible pump |
| MFG.: | Sulzer |
| HEAD: | 760' to 730' |
| R.P.M.: | 1500 |
| H.P.: | 11, 100 - 10, 300 (Metric) |
| REMARKS: | Pump can be used in a turbine |

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | None |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | (Empty Reservoir for repairs) |

DISCHARGE:

| | |
|---|---|
| TYPE: | Needle |
| MANUFACTURER: | Charmilles (Geneve) |
| SIZE: | 27.5" (700 mm) |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | 90% - 2 - 3 Sec.; 1-% - 15-20 Secs. |
| EMERGENCY: | Same |
| REMARKS: | Auxillary Seat on Pump Side - Adjust seat on pump side. Some reverse rotation on power failure - 100-200 RPM |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | - |
| NO. & SIZE: | - |

| | |
|---|---|
| MATERIAL: | - |
| TYPE OF UPPER GATE: | No data |
| SURGE TANK: | At pump end of tunnel |
| REMARKS: | Tunnel also has at least two collectors.<br>Two 59" Penstocks on suction - (79" on upper end) |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Glacier Melt |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | Water collects in large reservoir 88 million $M^3$ - Mica settles out in several days. |

## MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | Summer only |
| STARTS/DAY: | 17 max. |
| HOURS OF OPERATION: | I- 7260 II- 7400<br>(Maximum 12% of the time) |
| UNPLANNED OUTAGES: | None |
| CAUSE: | - |
| INSPECTION SCHEDULE: | - |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | - |
| TIME REQUIRED: | 4 - 6 weeks |
| IMPELLER CAVITATION: | None |

| | |
|---|---|
| SEAL RING WEAR: | Yes |
| NOISE LEVEL-START: | Quiet |
| NOISE LEVEL-RUN: | A-94; B-96; C-97 (Disch. Valve Chamber - C-112) |
| VIBRATION: | None |
| REMARKS: | Impeller shows erosion on inlet. Must be reground every 1000 hrs. and repaired (in Sulzer's shop) every 2000 hrs.<br><br>Wearing rings repaired twice at 1000 hr. intervals, then replaced. |

## GENERAL REMARKS

The Stafel pumping station was put into operation for the first time in December 1960 and was officially commissioned in the following spring. The station was erected in a moraine hollow at the foot of the north face of the Matterhorn; it lies along a siphon of the main tunnel, to which it is directly connected.

In the summer months the water coming from the catchment area is first passed through sand traps and is then collected in an equalizing basin 25 m above Stafel Pumping Station (Fig. 16-1). From here it is raised by the three storage pumps into the main tunnel, through which it flows with the gravity water into Grande Dixence Reservoir.

If on certain days the melting of the snows causes a big increase in the flow of water from the higher regions, the amount of water pumped can be adapted to the maximum flow in the main tunnel by means of a hydraulically controlled bypass with an energy dissipator. This method of control -- which is in any case not used very frequently, has proved to be more economical than throttling in the shut-off valves of the pumps. The three straightway annular quick-closing valves, supplied, like the throttle valve in the bypass, by Charmilles, close automatically under the direct action of the pressure in the pipeline as soon as the control-oil pressure ceases to act.

In the winter months the shut-off valve in the main siphon is closed. The water coming from Seickern is used for driving one of the three reversible machines, which now operates as a turbine, after which it flows into the equalizing basin and thence to the old Zermatt Power Station at a lower altitude.

Each of the three sets installed consists of a Brown Boveri motor-generator and a Sulzer single-stage double-flow pump-turbine designed for the operating data given in the following table:

| OPERATION AS: | | PUMP | TURBINE |
|---|---|---|---|
| Water Flow | $m^3/sec$ | 3.2-3.38 | 4.15-4.04 |
| Total delivery head | m | 218-208 | -- |
| Net Head | m | -- | 232-222 |
| Speed | r.p.m. | 1,500 | 1,500 |
| Rating of motor-generator | h.p. | 12,000 | |

As an adequate positive suction head was available, the high speed of 1, 500 r.p.m. was adopted, permitting compact design with good hydraulic characteristics. The resulting reduction in weight was very welcome in view of the difficulties of transport to this mountain site.

The motors are switched on direct under the full main voltage. The damping due to the long electric supply line and the specially attuned electrical properties of motors and transformers are sufficient to keep the starting current within the admissible limits. Moreover, this peak is reduced according to the number of sets in operation, as part of the reactive power required for starting is supplied by the motors already switched on.

While the sets installed in Stafel Pumping Station are today started and stopped from the control room in the station itself, the course of the further development of the Dixence scheme remote control from Z'Mutt Pumping station will be introduced. Pump or turbine operation is set by a preselector switch on the control desk at Stafel, which has been supplied by Panel AG. Actuation of the corresponding switch of a given set then initiates the sequence of starting or stopping operations, which follow each other automatically and in a fixed order.

While the units were designed to operate as reversible pump turbines, due to damaged system conditions they are at present used for pumping only.

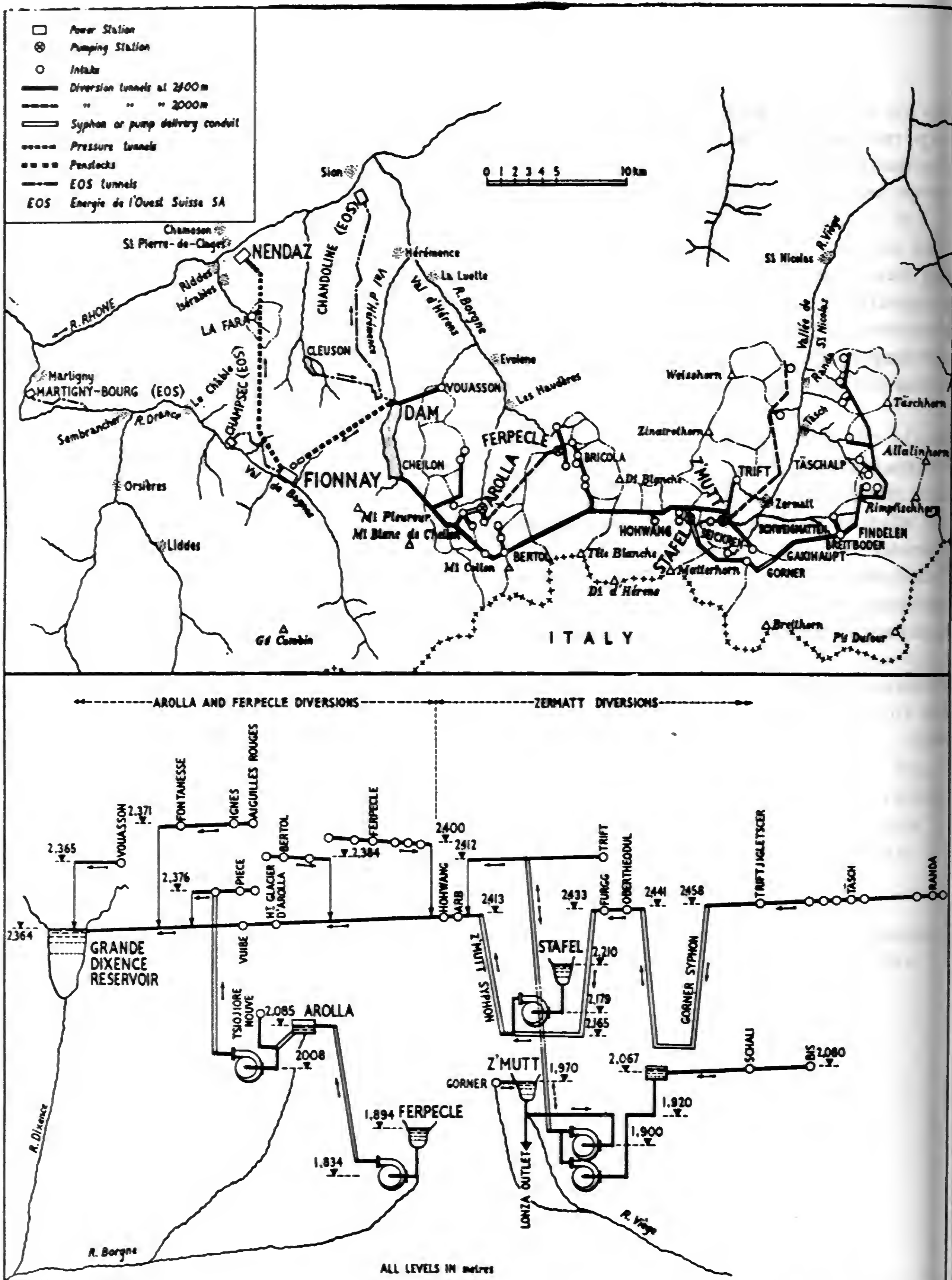



Fig. 16.0 - Grande Dixence System

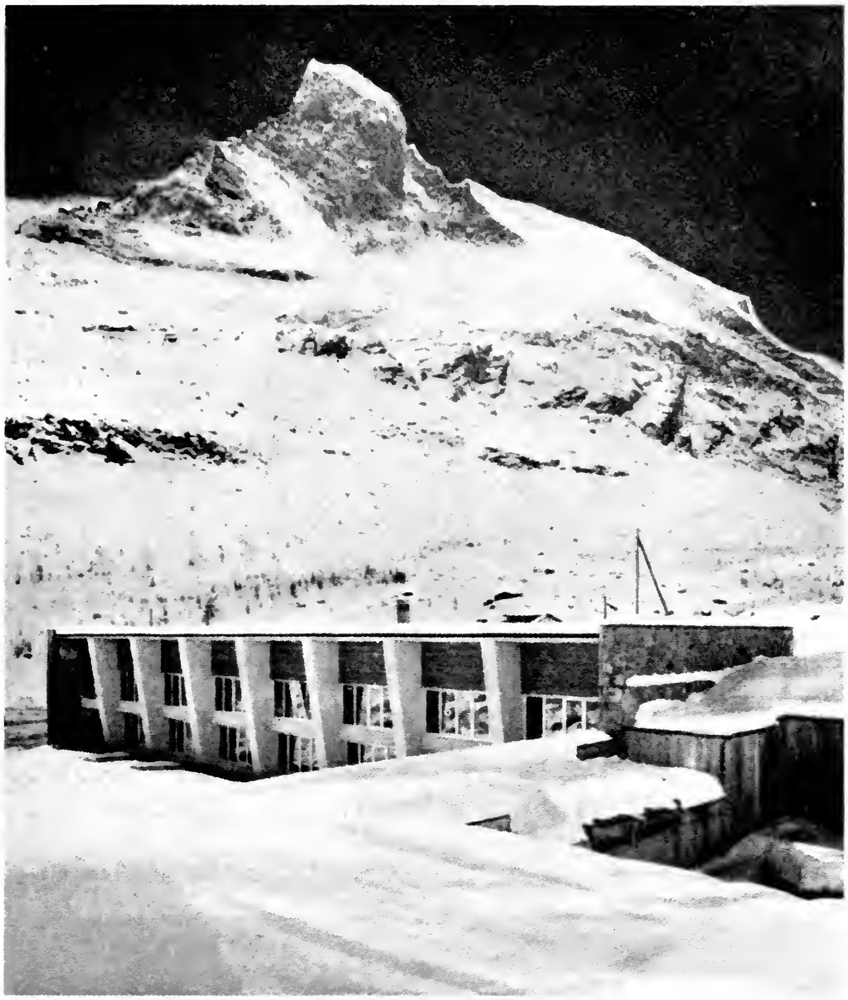


Fig. 16.1 - Stafel Pumping Station with Matterhorn in background.


Fig. 16-2 (G5-170)Entrance to Staffel Plant

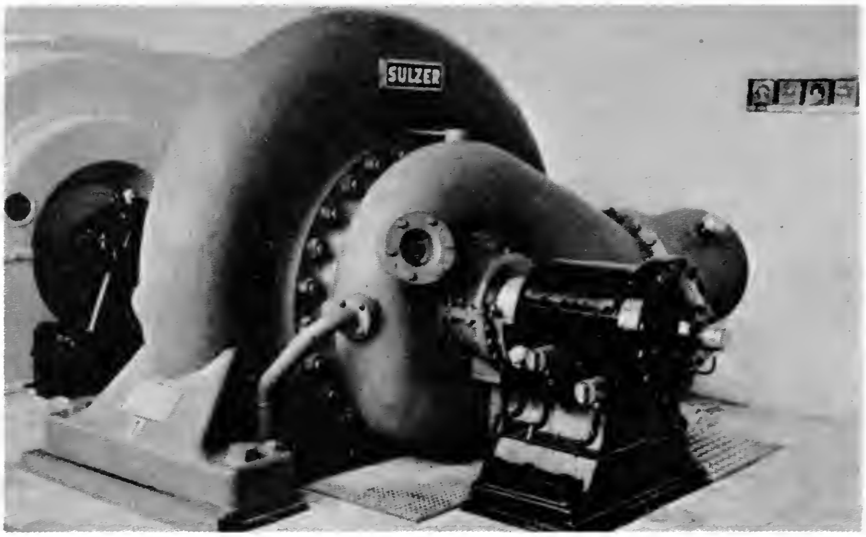



Fig. 16.3 (W8-1) Sulzer Pump


Fig. 16.4 (G5-18) Interiof of Station

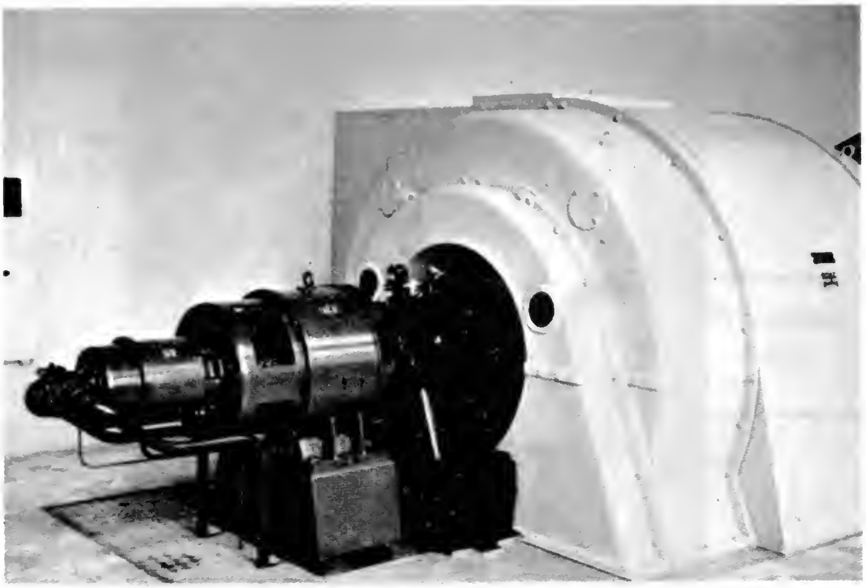


Fig. 16.5 (W8-2) Brown Boveri Motor

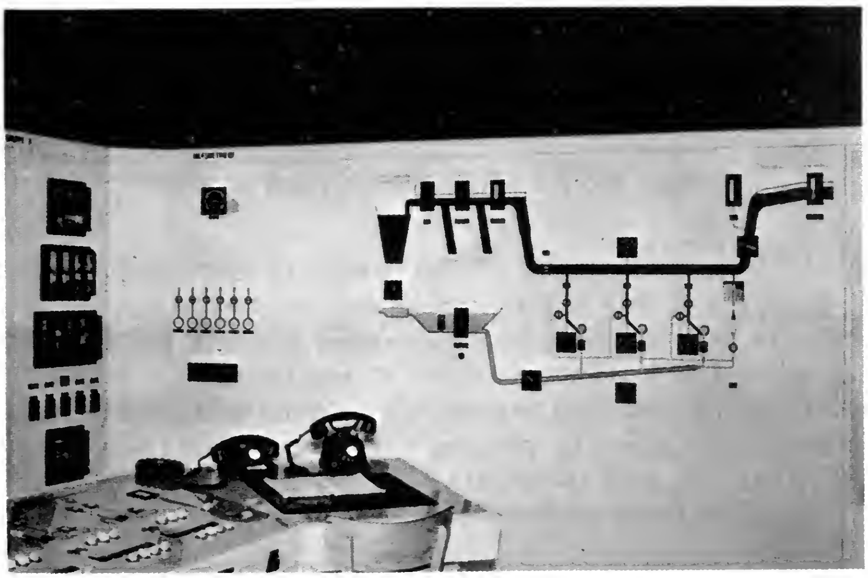
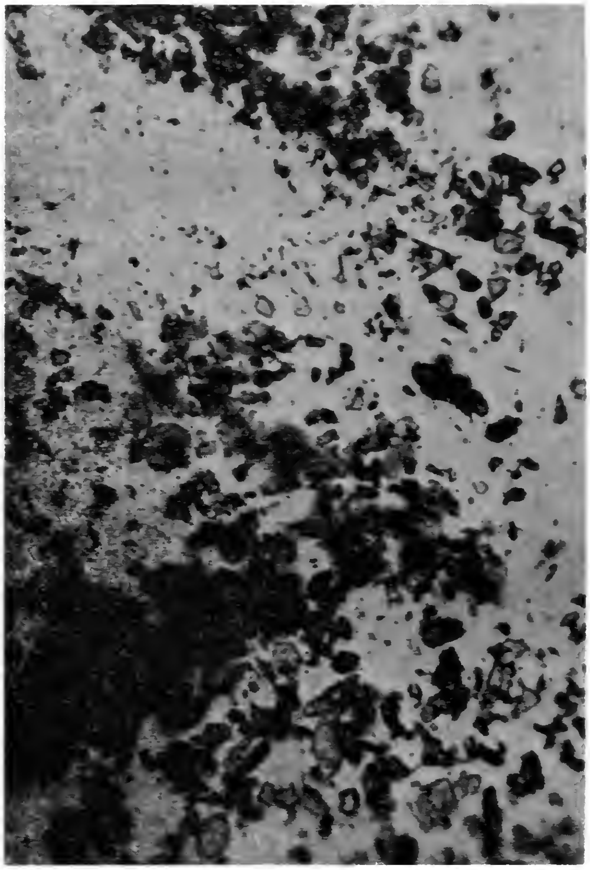


Fig. 16.6 (G5-23) Control Board



Stafel 70X

Fig. 16. 7 - Microphotograph of Silt

Silt Analysis: (STAFEL)

Microscopic analysis of this silt indicated that it consisted chiefly of colorless crystals with the general appearance of white sand. The major portion of the particles was in the 50 to 150 micron size. The silt was insoluble in mineral acids, and showed a hardness somewhat greater than glass. This was determined by placing some of the material between two microscope slides, and with moderate pressure, rubbing the two slides together. Slight scratching of the slides was observed.

The major mineral constituents were not determined, since the hardness, particle size, etc., would appear to be the more significant criteria of the abrasive action of the silt. The crystals were definitely sharp and well defined, and would be expected to be moderately abrasive to softer materials.

## Vibration Records

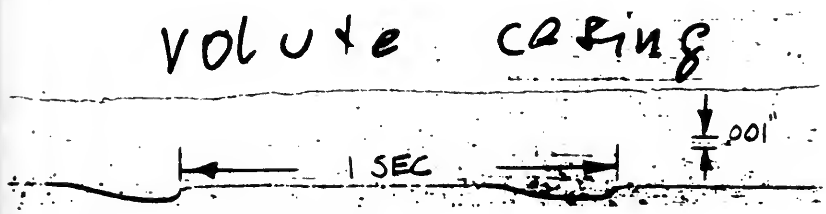
Grange Dixence SA, Lausanne, Switzerland

Plant : Stafel (surface power house)

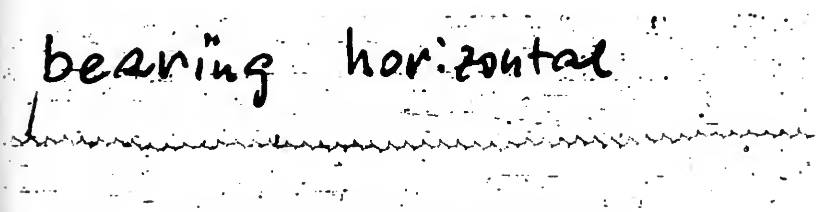
Units : three, single-stage, double flow, horizontal pumps; 10,500 HP, 117 cfs, 696 ft, 1500 RPM

Records-taken : July 22, 1964

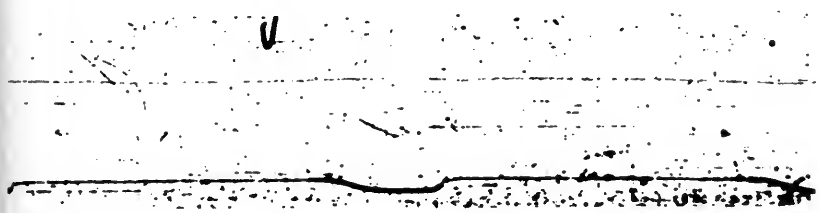
Normal Pump Operation




1. Unit 1, Volute casing




2. Unit 1, Middle bearing, transverse direction



3. Unit 1, Pump bearing, transverse direction

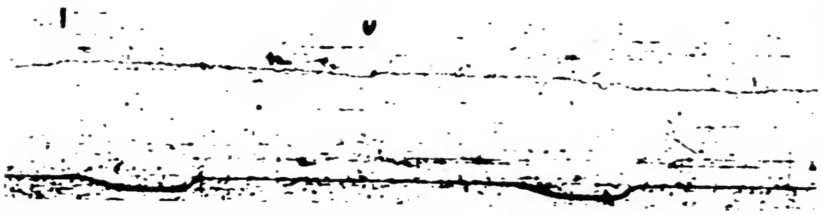
| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| ---- | less than .0002 |
| 7800<br>1500 | .0003<br>.0007 |
| ---- | less than .0002 |

Figure 16. 8

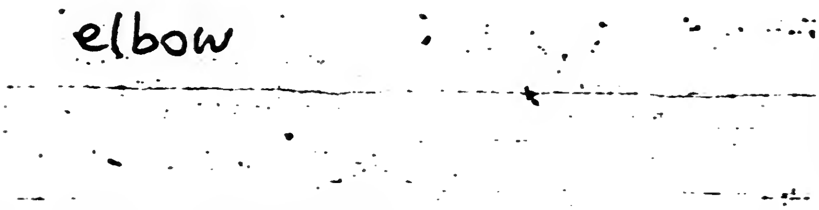
Grange Dixence SA, Lausanne, Switzerland

Plant : Stafel (surface power house)

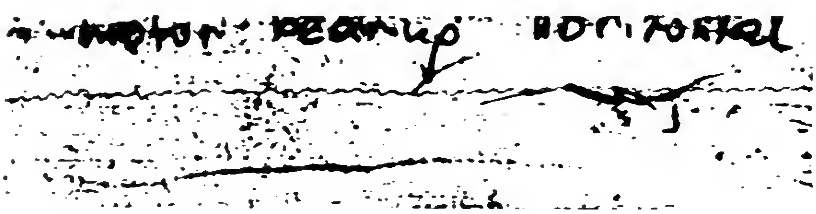
Normal Pump Operation (cont.)



4. Unit 1, Pump bearing, axial direction




5. Unit 1, Suction elbow



6. Unit 1, Motor bearing, transverse direction

| Record | Frequency c.p.m. | Average Amplitude inches |
|---|---|---|
| 4 | 7800 | less than .0002 |
| 5 | ---- | less than .0002 |
| 6 | 4500 | .0003 |

Figure 16.8-2

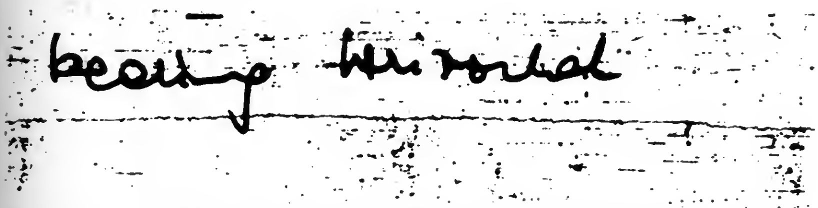
## Vibration Records (cont.)

Grange Dixence SA, Lausanne, Switzerland

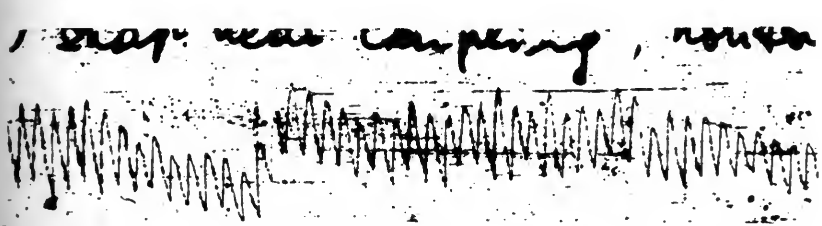
Plant : Stafel (surface power house)

### Normal Pump Operation (cont.)

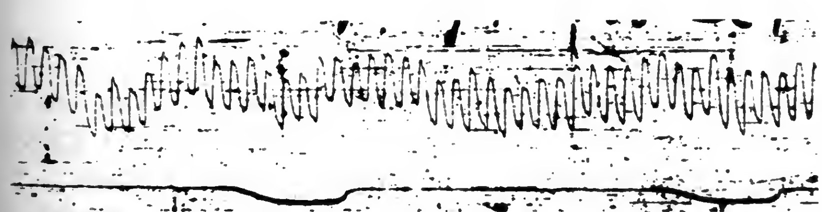
7. Unit 2, Motor bearing, transverse direction




8. Unit 2, Middle bearing, transverse direction



9. Unit 2, Pump shaft near coupling, transverse direction



10. Unit 1, Pump shaft near coupling, transverse direction

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 7500 | less than .0002 |
| 1500 | .0005 |
| ---- | less than .0002 |
| 1800 | .0040 |
| 1500 | .0045 |

Figure 16. 8-3

PLANT NAME: MOTEC

REPORT NO.: 17

| | |
|---|---|
| LOCATION-ALTITUDE: | Near Chippis, Switzerland - 5130' |
| OWNER: | Kraftwerke, Gougra A.G. |
| ADDRESS: | Siders, Switzerland |
| TYPE OF PLANT: | Pump Storage - Generation - Surface |
| SERVICE | Utility Power and Aluminum Production |
| TYPE OF WATER: | Poor - Glacial Melt and Rain |
| UNITS INSTALLED: | One 3-stage single suction horizontal, with double Pelton turbine and generator-motor. |
| HORSEPOWER: | 30,700 (750 RPM |
| CFS: | 115.1 |
| STATIC HEAD: | 2240' - Moirn - 2000' - Tourtemagne |
| PLANT STARTED: | July 1959 |
| VISITED BY: | Gartmann - Hartmann - Westman |
| DATE: | July 23, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Mr. Baumgartner<br>Mr. Fischer |

REMARKS: Plant floor approx. 187' x 33.4'. Pump has booster in suction. Sulzer vertical deep well two-stage, 115.1 CFS - 85.4 ft., 510 RPM, Pelton turbine (Charmille). Gear coupling between pump and motor. Hydraulically operated plant also contains Voith single-stage, horizontal (syphon) pump 282'-434'; 225 to 149 CFS = 8500 HP to 8650 HP.

## PUMPS:

| | |
|---|---|
| TYPE: | 3-stage, single suction - horizontal |
| MANUFACTURER: | Sulzer |
| SIZE DISCHARGE: | 27.6" (700 mm) |
| SIZE SUCTION: | 39.4" (1000 mm) |
| RPM: | 750 |
| CFS: | 98.2 - 115.1 - 138.1 |
| HEAD: | 2110' - 2064' - 1870' |
| H.P. REQUIRED: | 27,000 - 30,300 - 33,800 |
| N s.: | 1270 |
| INSTALLED: | July 1959 |
| HRS. OF OPERATION | 7923 (approx. 1500 hrs. per year) |
| MIN. SUBMERGENCE: | 49.2' |
| NORMAL SUBMERGENCE: | 49.2' |
| MAX. SUBMERGENCE: | 55.8' |
| REMARKS: | Submergence determined by head on booster pump. |

## EFFICIENCIES:

| | | | |
|---|---|---|---|
| MODEL GUARANTEE: | No Model | | |
| MODEL ACTUAL: | H = 2115' | 2040' | 1870' |
| PROTOTYPE-GUARANTEED: | 88 | 89 | 87 |
| PROTOTYPE-ACTUAL: | 87.6 | 88.4 | 88.9 |
| METHOD OF TEST: | Current meter in discharge. | | |

## CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 27.6" (700 mm) |
| DIAMETER IMPELLER: | 62.25" (1580 mm) |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 16.5" $\pm$ |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | Stainless steel - 13/2 |
| MATERIAL IMPELLER RINGS: | Bronze |
| MATERIAL-CASING RINGS: | Cast Iron |
| RADIAL CLEARANCE: | 0.75 mm |
| MATERIAL BALANCING RINGS: | Turbine Bronze |
| MATERIAL INTERSTAGE SEAL: | 2% Ni Cast Iron |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | 13% Chrome |
| BEARING: | Babbitt - 13.8" x 17.25" |
| THRUST BEARING: | Single - Kingsbury outboard force-feed lubrication - Oil pump attached to shaft. |

| | |
|---|---|
| TYPE OF PACKING: | Mechanical |
| MATERIAL OF PACKING: | Four Babbitt lined bronze rings |
| MATERIAL OF SLEEVE: | 13% Cr. |
| CLEARANCE: | 0. 35 mm |
| REMARKS: | Diaphragm-Ductile Iron - Balancing rings (5) Labyrinth-double stationary rings C. I. (changed to Stainless Steel in 1961) 0. 75 mm Clearance. |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Horizontal - Synchronous direct connected exciter outboard from turbine. |
| MANUFACTURER: | Brown Boveri |
| H.P.: | Generator - 29 MVA - Motor 37, 500 HP |
| R.P.M.: | 750 |
| VOLTAGE: | 9000 |
| STARTING: | By Turbine |
| REMARKS: | 98. 2% Efficiency at Unity PF<br>97. 6% Efficiency at 80% " |

TURBINE:

| | |
|---|---|
| TYPE: | Double Pelton Type |
| MFG.: | - |
| HEAD: | 1835' to 2220' |
| R.P.M.: | 750 |
| H.P.: | 25, 600 to 31, 800 |

VALVES:

| | |
|---|---|
| INTAKE: | None - Pump above water line |
| TYPE: | - |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | - |

DISCHARGE:

| | |
|---|---|
| TYPE: | Spherical |
| MANUFACTURER: | Von Roll |
| SIZE: | 27.5" (700 mm) |
| OPERATION: | |
| OPENING: | Hydraulic (Water) |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | - |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | One 4.77' - 5.1' - 5.4' |
| LENGTH: | Horizontal 575'; 80% slope - 2870' into tunnel<br>7.9' dia. - 11,100' long |

| | |
|---|---|
| MATERIAL: | Steel lined |
| TYPE OF UPPER GATE: | Two Butterfly |
| SURGE TANK: | At end of Penstock |
| REMARKS: | Lower 1140' - 11.13 mm steel<br>Upper 1425' - 8-11 mm steel |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Poor - Glacial Silt - Dust |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | Contains sharp particles |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | 1500 hrs. per year |
| STARTS/DAY: | - |
| HOURS OF OPERATION: | 7923 (7/13/64) |
| UNPLANNED OUTAGES: | Three in 1962 |
| CAUSE: | Overheating of Coupling |
| INSPECTION SCHEDULE: | - |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | Once per year |
| TIME REQUIRED: | 15 days (estimated) |
| IMPELLER CAVITATION: | No |

| | | | |
|---|---|---|---|
| SEAL RING WEAR: | Yes | | |
| NOISE LEVEL-START: | A- | B- | C- 105 |
| NOISE LEVEL-RUN: | A- 96; B- 99; C- 101 | | |
| VIBRATION: | None | | |

REMARKS: No cavitation noise.

Labyrinth seal rings must be replaced each two years.

Balancing seal leakage was 30 L/S (475 GPM) when new. Increased to 37 L/S (585 GPM) after 650 hrs. of operation (May 1960). By Winter 1960 leakage increased to 55 L/S (870 GPM) at which time they were replaced. Replaced again in 1963/4. Much sand in 1963. Rings should be replaced again now. Leakage 55 L/S.

Seal rings on spherical valve had to be replaced due to sand erosion. This now necessary again.

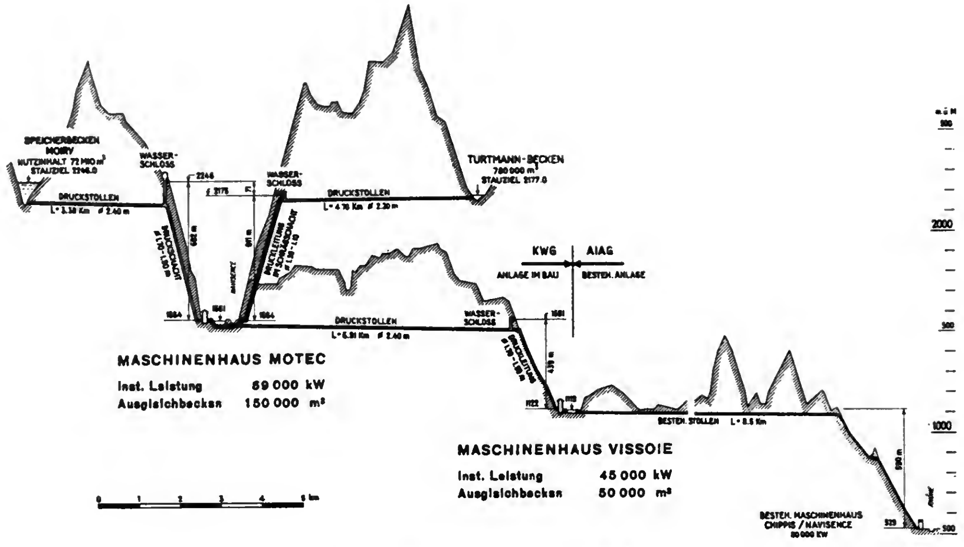
Diffusers show slight erosion. None on impellers.

## GENERAL REMARKS

Motec Power Station is the uppermost step of a three-stage power scheme realized by Gougra, AG, Sierre, and Aluminum-Industrie AG, Chippis/Zurich, as part of the development of the water power in the Canton of the Valais, Switzerland. Of the three double Pelton turbine sets installed in this station, with a total rating of 69,000 kW, two can be coupled to pumps. One of these pumps is an Escher Wyss booster unit requiring 7,000 to 10,000 HP and operating under a positive suction head of 613 meters; it serves to equalize the pressure between the reservoir formed by the construction of an arched gravity dam in the Turtmann Valley and the reservoir at Moiry, 72 meters higher. The other is a Sulzer storage pump with a rating of 30,000 to 34,000 HP, which raises the waters of the Navisence collected in the equalizing basin near Motec Power Station into the storage reservoir 685 meters higher at Moiry.

The water thus raised can later be utilized in three stages, at Motec, Vissoie and Chippis in the Rhone Valley, with a total available head of 1,720 meters.

As a result of this high head within a horizontal distance of no more than 20 kilometers, together with the high efficiencies of the hydraulic and electric machines, a single kilowatt-hour expended on pumping in the summer months yields no less than 1.75 kWh of valuable energy in winter.




KRAFTWERKE GOUGRA, LÄNGENPROFIL

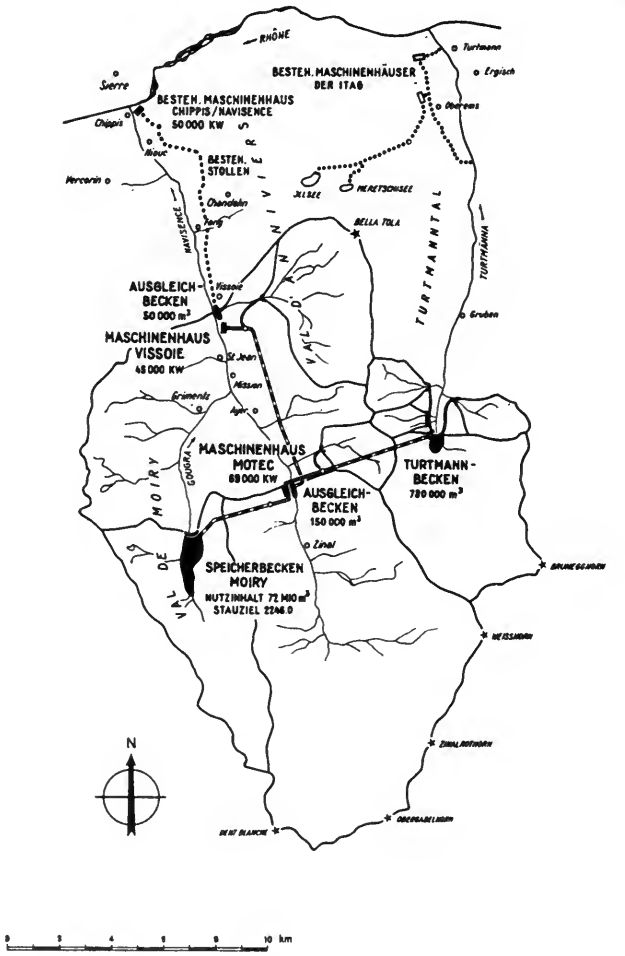



Fig. 17.1 and 17.2

Profile and Plan of Gogra System showing location of Motec Plant.

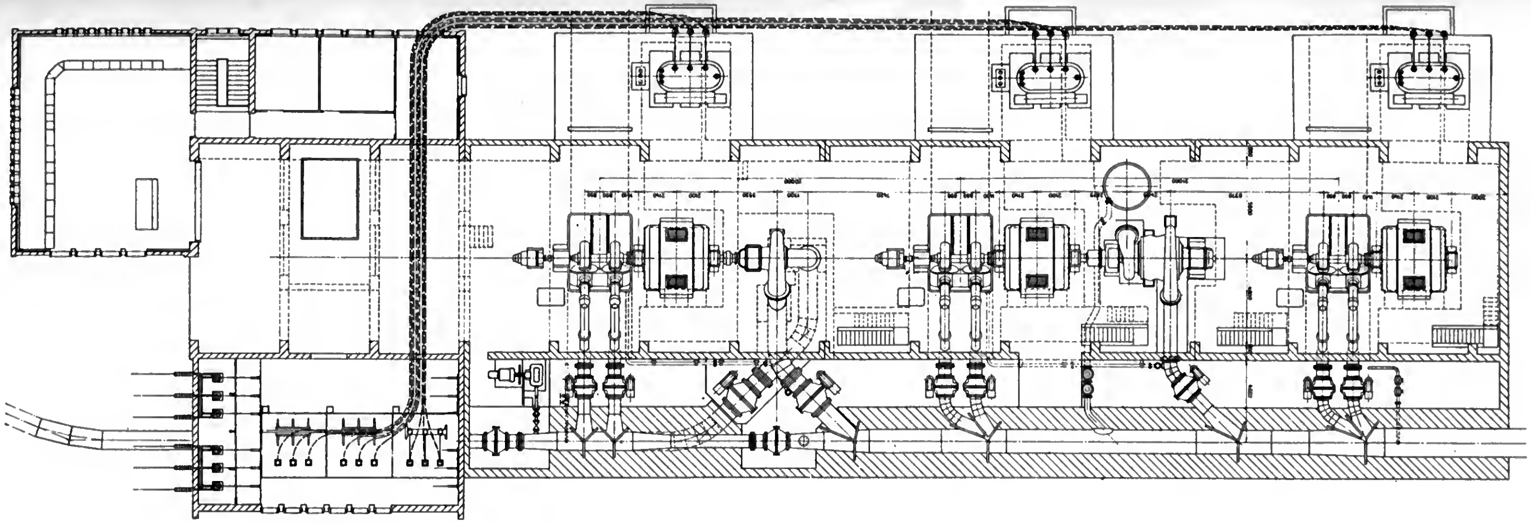


Fig. 17.3 - Plan of Station - Storage pump in center.

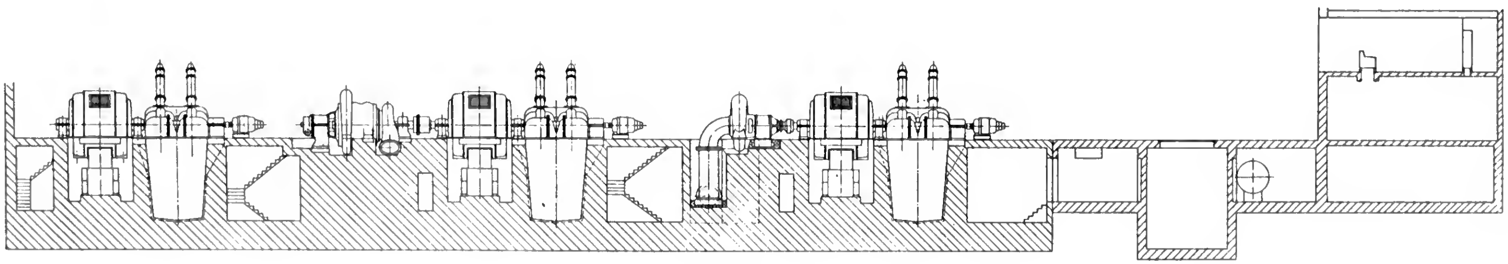


Fig. 17.4 - Longitudinal Section of Station.

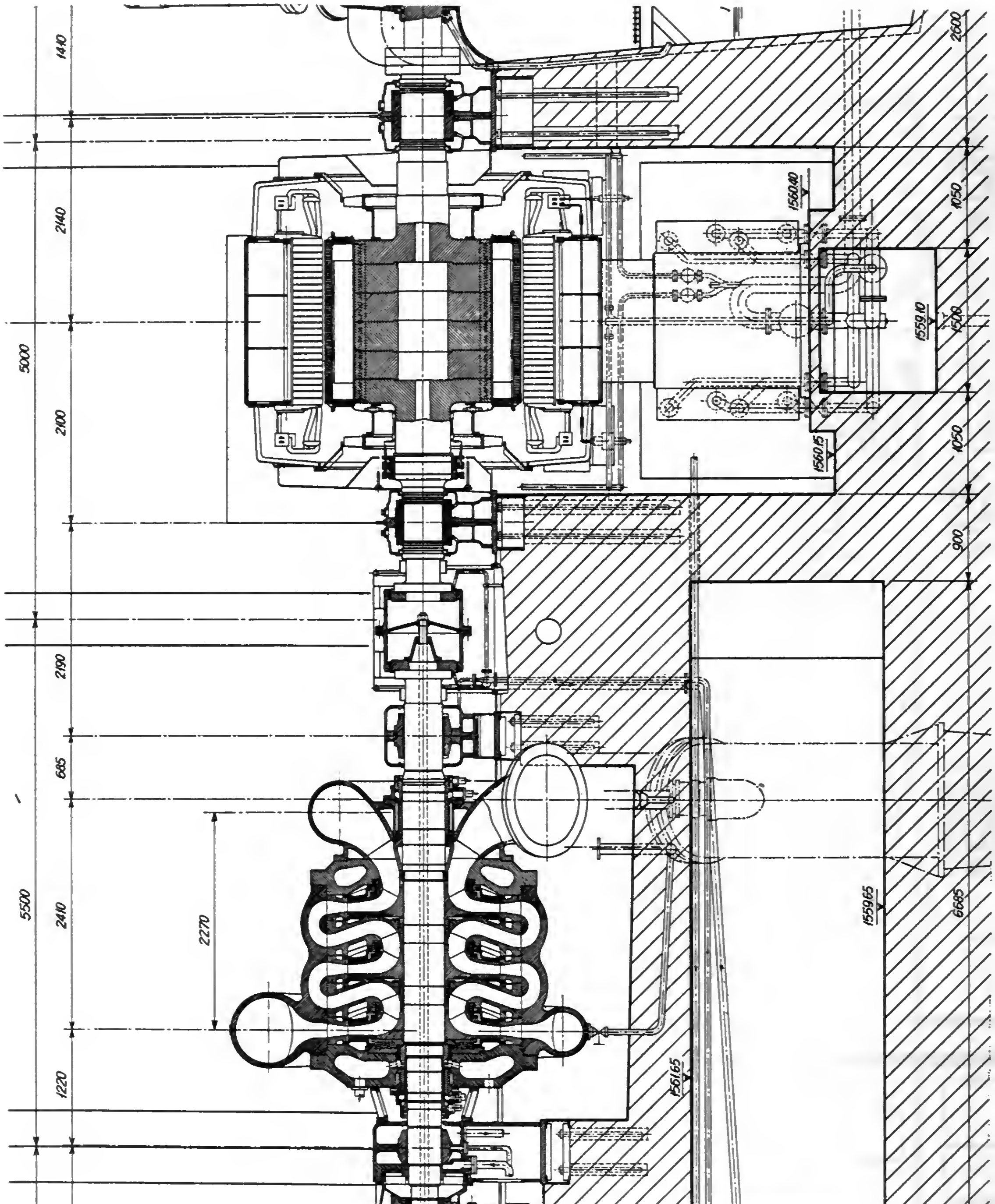



Fig. 17.5 - Cross Section through Pump and Motor.

Fig. 17.6 (W830) Exterior of Motec plant.

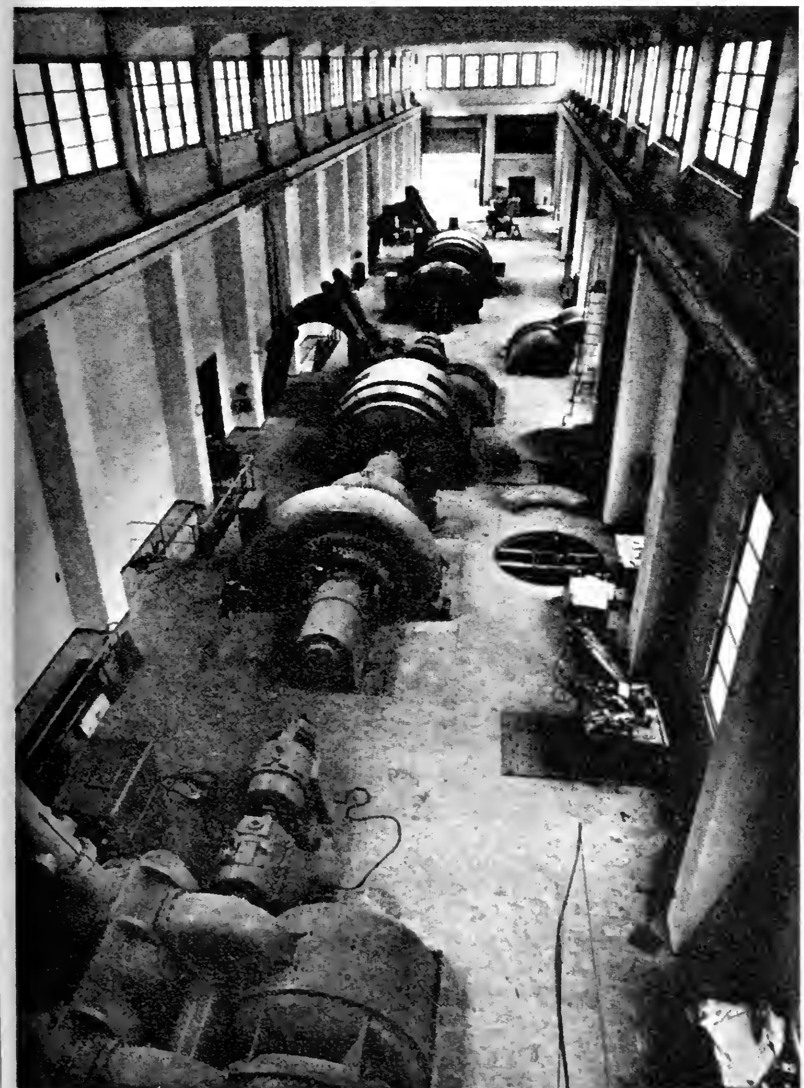


Fig. 17.7 - Interior of Motec Plant. Pumping unit in center.


Fig. 17.8 (W8-21) Suction end of Sulzer Pump

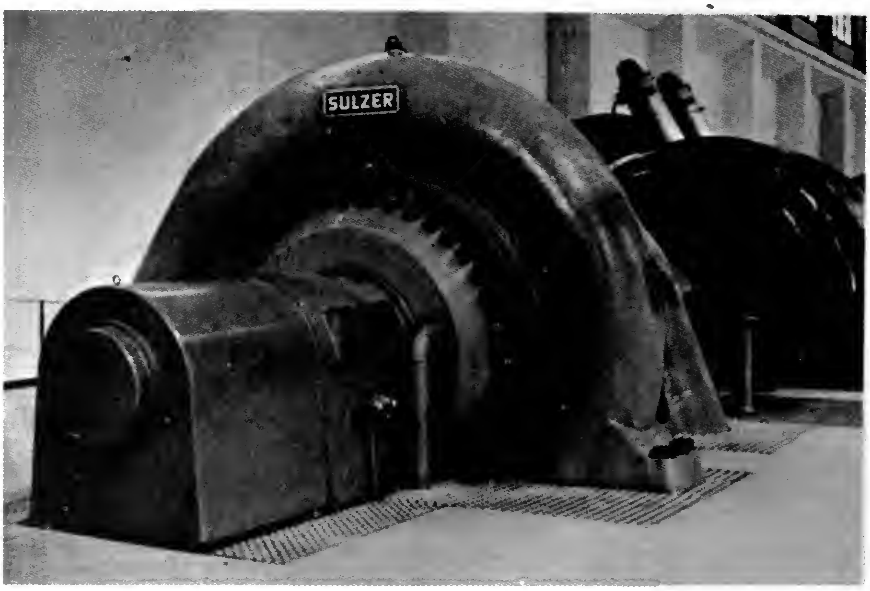



Fig. 17.9 (G5-34) Discharge end of Sulzer Pump

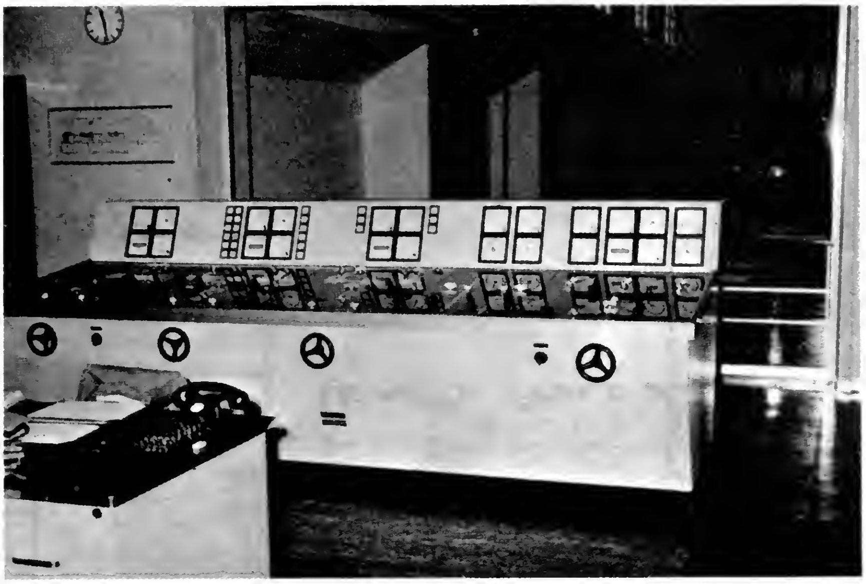


Fig. 17.10 (W8-16) Electrical Control Stand

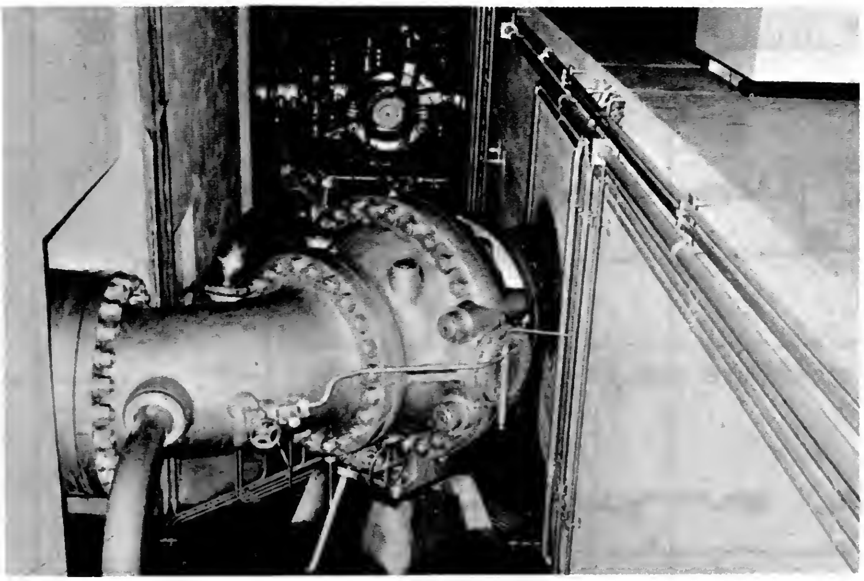


Fig. 17.11 (W8-23) Von Roll Discharge Valve

## Vibration Records

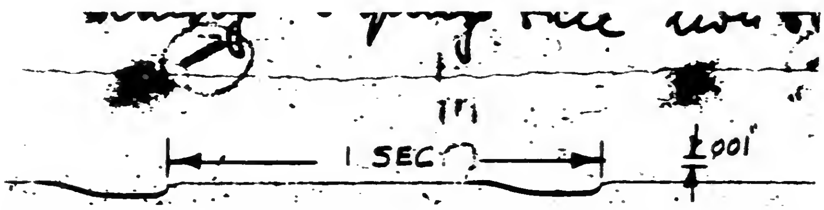
Kraftwerke Gougra AG, Siders, Switzerland

Plant : Motec (surface power house)

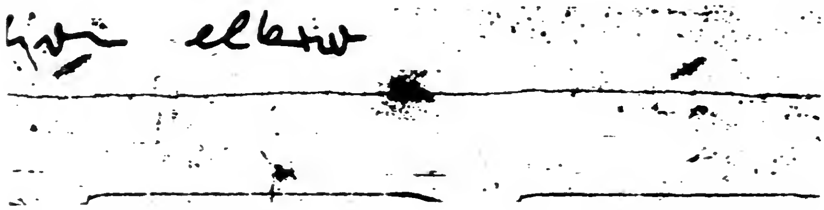
Units : one, 3-stage, single flow, horizontal pump;
30,700 HP, 115 cfs, 2060 ft, 750 RPM

Records-taken : July 23, 1964

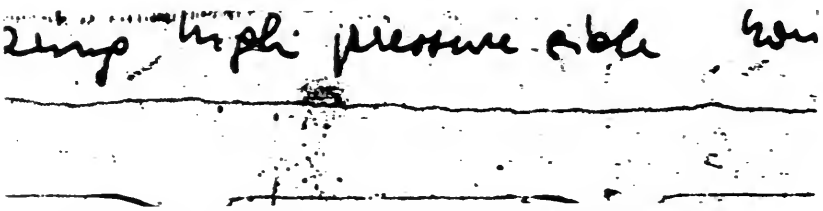
Normal Pump Operation



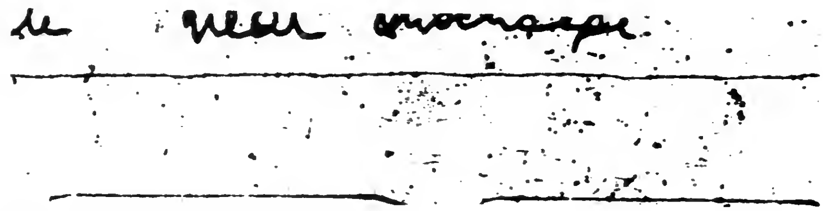

1. Bearing, coupling side, transverse direction



2. Suction elbow



3. Bearing, high pressure side, transverse direction



4. Volute near discharge

| Record | Frequency c.p.m. | Average Amplitude inches |
|---|---|---|
| 1 | ---- | less than .0002 |
| 2 | ---- | less than .0002 |
| 3 | 7200 | .0003 |
| 4 | ---- | less than .0002 |

Figure 17-12

Vibration Records (cont.)

Kraftwerke Gougra AG, Siders, Switzerland

Plant : Motec (surface power house)

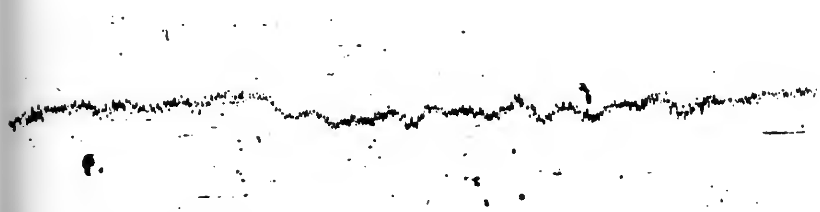
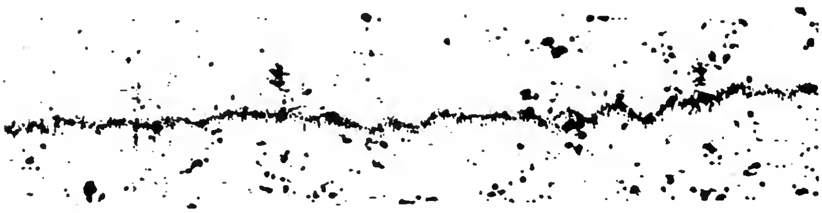
| Spherical Discharge Valve-during shutdown process | Frequency c.p.m. | Average Amplitude inches |
|---|---|---|
|  5. Valve closing | 5000 | .0006 |
|  6. Valve closed | 6600 | .0008 |
|  7. Speed drops | 5400 | .0005 to .0003 |

Figure 17-13

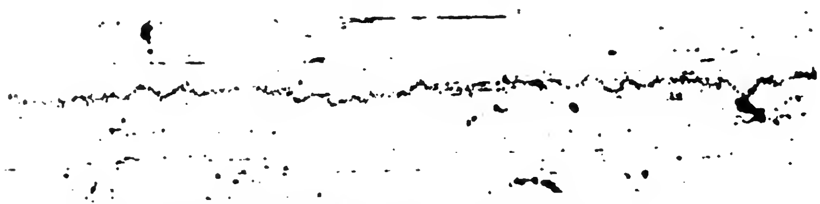
Kraftwerke Gougra AG, Siders, Switzerland

Plant : Motec (surface power house)

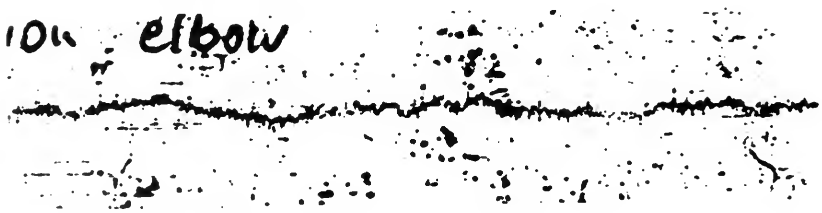
## During Starting Process



8. Volute near discharge



9. Bearing, coupling side, transverse direction



10. Suction elbow

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 9000 | .0007 |
| 9000 | .0005 |
| 9600 | .0008 |

Figure 17-14

PLANT NAME: HERDECKE (KOEPPCHENWERK)

REPORT NO.: 19

| | |
|---|---|
| LOCATION-ALTITUDE: | Near Essen, Germany - 318' - Ruhr River |
| OWNER: | Rheinisch, Westfälisches Elekitätswerk A. G. |
| ADDRESS: | Essen, Germany |
| TYPE OF PLANT: | Surface |
| SERVICE | Power Generation - Pump Storage |
| TYPE OF WATER: | River Water - Poluted |
| UNITS INSTALLED: | 4 - Horizontal - Two-Stage - Double Suction Pumps with Generator and Francis Turbine, and Starting Pelton Turbine |
| HORSEPOWER: | 3 x 32,500 - 1 x 35,500 (300 RPM) |
| CFS: | 495 (516 Max.) |
| STATIC HEAD: | 550' |
| PLANT STARTED: | 3 in 1930 - 1 in 1949 |
| VISITED BY: | Westman - Gartmann - Hartmann |
| DATE: | August 4, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | B. Georgi, Plant Supt., Herdeke<br>K. Parzany, Chief Electrical - Mechanical Engineer for RWE |
| REMARKS: | Power House 525' x 65.5', built on a concrete slab 13' below river bed.<br><br>125% of capacity of upper reservoir used daily, Pumping and turbining. |

PUMPS:

| | |
|---|---|
| TYPE: | Horizontal - Tw0Stage, Double Suction |
| MANUFACTURER: | Voith - Sulzer (Jointly) |
| SIZE DISCHARGE: | 67" |
| SIZE SUCTION: | 2 x 43. 3" |
| RPM: | 300 |
| CFS: | 495 |
| HEAD: | 508" |
| H.P. REQUIRED: | 32, 100 |
| N s.: | 1560 |
| INSTALLED: | 3 in 1930; 1 in 1949 |
| HRS. OF OPERATION | No. II - 83, 613; No. III 83, 384<br>Now operate about 3000 Hrs./Yr. Each |
| MIN. SUBMERGENCE: | Minus 2. 3' |
| NORMAL SUBMERGENCE: | 0 |
| MAX. SUBMERGENCE: | 0 |
| REMARKS: | - |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | Not Available |
| MODEL ACTUAL: | " " |
| PROTOTYPE-GUARANTEED: | " " |
| PROTOTYPE-ACTUAL: | 86% 89% |
| METHOD OF TEST: | - |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 67" |
| DIAMETER IMPELLER: | 98.5" |
| DIAMETER EYE: | 60.5" |
| DIAMETER SHAFT: | 29.5" (Impeller Bolted to Shaft) |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | Bronze (Later replaced with Stainless Steel) |
| MATERIAL IMPELLER RINGS: | Bronze (Change to Stainless Steel) |
| MATERIAL-CASING RINGS: | Cast Iron |
| RADIAL CLEARANCE: | 1 mm |
| MATERIAL BALANCING RINGS: | None |
| MATERIAL INTERSTAGE SEAL: | Babbitt against shaft |
| RADIAL CLEARANCE: | 1.5 mm |
| MATERIAL DIFFUSER: | Bronze |
| BEARING: | - |
| THRUST BEARING: | Collar Bearing only on pump. |

TYPE OF PACKING: Fixed - Mechanical

MATERIAL OF PACKING: Carbon Rings - Babbitt

MATERIAL OF SLEEVE: Steel

CLEARANCE: 0.3 - 0.4 mm

REMARKS: Carbon rings until 1955 - changed to Babbitt.

MOTOR OR GENERATOR:

TYPE: Horizontal - Synchronous

MANUFACTURER: I & II - SSW - III & IV - AEG

H. P. Generator 47,000 KW, Motor 32,500 - 35,500

RPM: 300

VOLTAGE: 11,250

STARTING: By turbine - also, hydro-mechanical clutch. Also starting turbine.

REMARKS: 1) Turbine valve closed; 2) air admitted; 3) Pump air admitted; 4) Pelton turbine put in operation, brought up to speed and coupled; 5) Air ejected; 6) Spherical valve opened; 7) Guide vanes opened.

TURBINE:

TYPE: Horizontal - Francis type

MFG: Voith

HEAD: 508' - 535'

RPM: 300

H. P.: 47,000 HP

REMARKS: Cavitation on inlet elbow. Original bronze impellers.

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | Stop locks for repair only |
| MANUFACTURER: | - |
| SIZE: | 36' wide |
| OPERATION: | - |

DISCHARGE:

| | |
|---|---|
| TYPE: | I, II, III - Spherical - IV - Needle |
| MANUFACTURER: | Voith |
| SIZE: | 67" (1700 mm) |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | One seal only - Penstock drained for repairing (Spherical valves preferred). |

PENSTOCK:

| | |
|---|---|
| SURFACE OR U. G. | Surface |
| NO. & SIZE: | 4 x (8.4' at bottom - 10.5' at top) |
| LENGTH: | 846' - then 16.4' tunnel - 229' long |

| | |
|---|---|
| MATERIAL: | Rivited Steel |
| TYPE OF UPPER GATE: | Two Butterfly Valves |
| SURGE TANK: | None |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | River Water - Poluted, but free of solids. |
| Ph: | Unknown |
| HARDNESS: | - |
| REMARKS: | Sometimes Acid - Sometimes Alkaline - Polution by Steel Works |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | - |
| STARTS/DAY: | 800 per year per pump |
| HOURS OF OPERATION: | No. II - 83,613<br>No. III- 83,384 |
| UNPLANNED OUTAGES: | Very rare |
| CAUSE: | - |
| INSPECTION SCHEDULE: | Yearly |
| TIME REQUIRED: | 5 - 6 days |
| OVERHAUL SCHEDULE: | Every 5 years |
| TIME REQUIRED: | 8 days |
| IMPELLER CAVITATION: | Yes |

| | |
|---|---|
| SEAL RING WEAR: | Some Corrosion |
| NOISE LEVEL-START: | 105 with closed valve |
| NOISE LEVEL-RUN: | 93 D. B. |
| VIBRATION: | Very little |
| REMARKS: | Repairs made in summer, while energy available from Austria, South Germany and Luxumberg.<br><br>Impellers: (First Stage)<br><br>No. 3 - Originally bronze. Repaired corrosion by welding on stainless steel patches - Replaced in 1964.<br><br>No. 2 - Replaced by chrome nickel in 1964.<br><br>No. 1 - Manganese steel until 1954; (5 yrs.) replaced by Cr. Ni in 1964. |

## GENERAL REMARKS

The power house has a length of 160 m and a width of 20 m. It is built on a concrete slab 4 m beneath the river bed. There are power units each with a horizontal shaft of 26 m long. Such a unit consists of the generator, working also as motor, with rigidly coupled water turbine and the pump with hydro mechanical coupling, running at 300 rpm. The total generator output is 132,000 kW, whereas the pumps have a total capacity amounting to 107,200 kW. Each of these pumps can lift 14.6 $m^3$ water per sec. The upper basin can therefore be filled within an eight hour working period. The stored water will produce 580,000 kWh at full load operation within 4.4 hours. The annual production was 152 million kWh in 1954 at 1970 hours of utilization. 292.5 million kWh were used for pumping for the same period thus showing that the plant was operated under an efficiency of 65.6 p.c. of the supplied pumping power. The load diagram shows power consumption and power delivery on a characteristic day.

Since great loss and some other difficulties occur if a pump impeller fixed to the alternator shaft always runs with the turbine-alternator a coupling was installed which may may be clutched in and declutched under full load. Three of these couplings were built on the Föttinger principle as hydro-mechanical friction clutches. The 4th set (of newer design) has been equipped with a starting turbine at the side of the pump. A geared clutch is brought in when after starting the normal number of pump revolutions is almost reached and there is only a slight difference of ± p.c.

The alternators, which during pump operation can also be operated as motors, were built by Messrs. A.E.G. and S.S.W. respectively. These units have been designed for a voltage of 10 kV, which by means of four transformers with a capacity of 40,000 kVA is stepped up to 220 or 110 kV. In a big switch yard which because of the small space between mountain-side and power house had to be erected according to a special superstructure design close behind the power house there are six transformers, having a total capacity of 360 MVA handling the distribution of the energy produced in the power station. Six 220 kV lines and four 110 kV lines form the connection to Brauweiler, to Siegerland, to Ibbenbüren in the north and Kelsterbach in the south, and also to the adjacent Mark Electricity Works.

It may be mentioned that in the whole of the plant labor has as far as possible been replaced by automatic control. Apart from the high-frequency and telephone communications, a special signaling line runs from the chief coupling point at Brauweiler to Herdecke in order to reduce the time which could be wasted by phoning. This is of great importance if the station has to be called up as an immediate reserve in case of trouble. Particularly during the last war when ever so many times the station had to be used for bringing lines up to voltage or to replace must lost generation capacity, the consumers, owing to Koepchenwerk's great readiness to take load, often were unaware of the fact that there were troubles if they did not incidentally observe the slight loss in voltage, when the fault occurred.

The Koepchenwerk station was also hit by the war. When on May 17th, 1943, the dam of the Möhne Lake was destroyed by bombs the whole power house was submerged as far as the shafts of the sets, and the switch yard, too, was immersed by 40 cm. The maximum admissable storage level of the Hengstey Lake was exceeded by 2.10 m by the flood wave which rushed with 5000 $m^3$ water per sec., i.e., with a water quantity 130 times bigger than normal water through the Ruhr Valley. After 10 weeks' hard work under primitive conditions the station was ready again for service, though the alternators could be re-wound only some years later. A lot of bombs were dropped on the station still in the last days of the war and a part of the switch yard was destroyed. These damages were soon cured, sometimes by temporary means at first, and this, too, justified this development even under most difficult conditions.

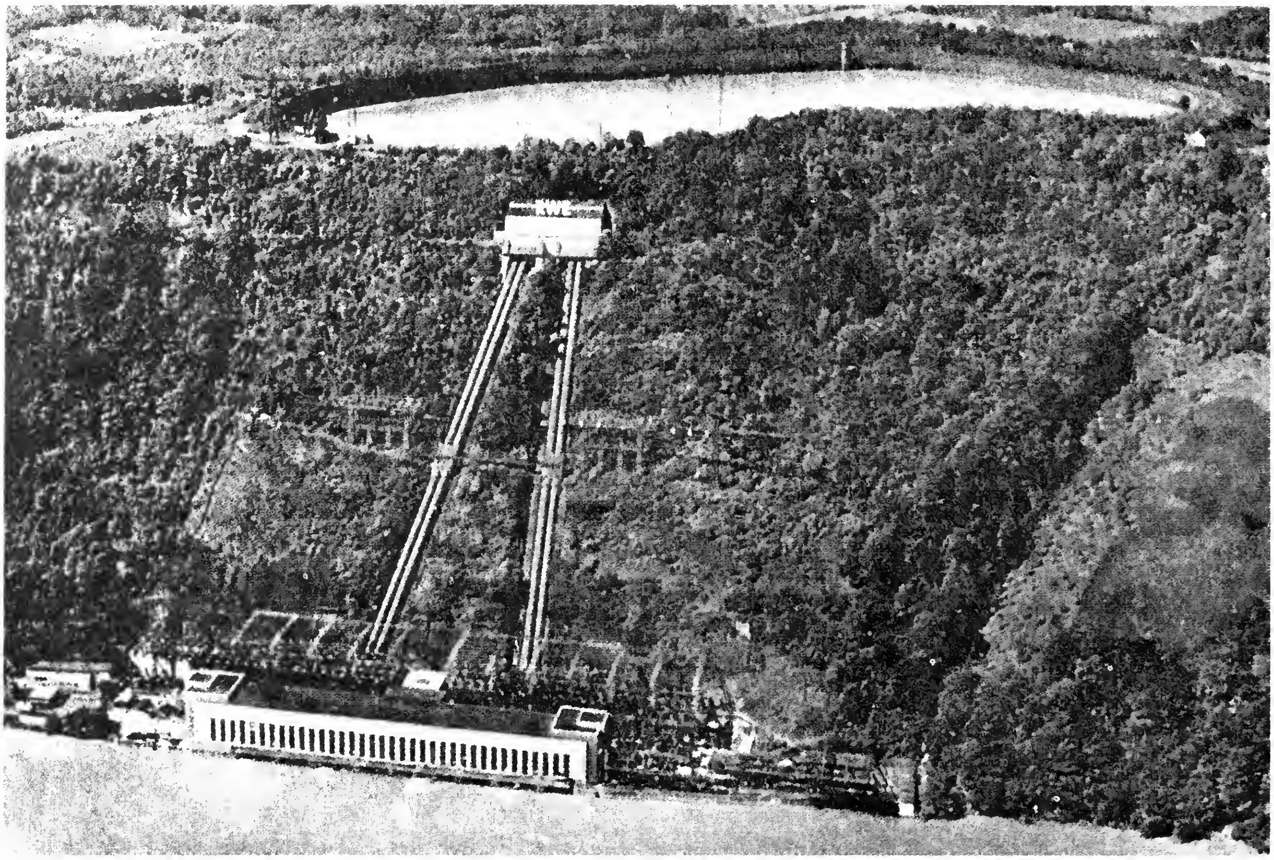


Fig. 19.1 - View of Power Plant.

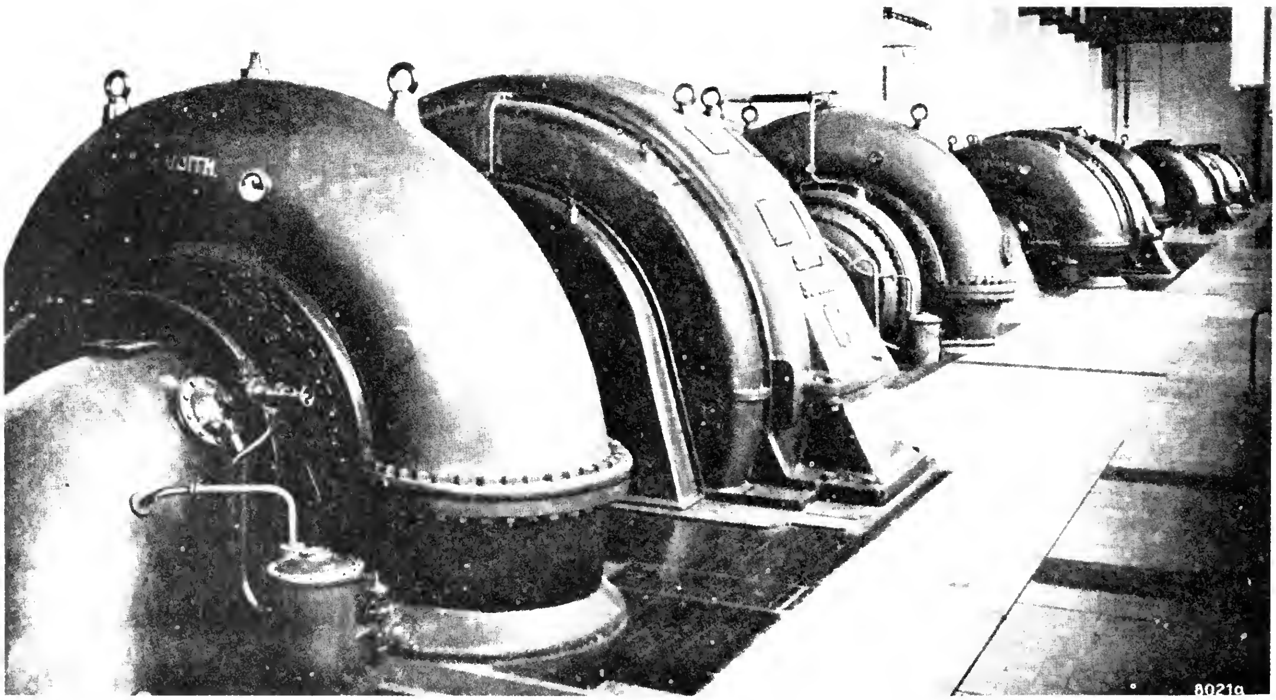


Fig. 19.2 - Interior of Pump Station.

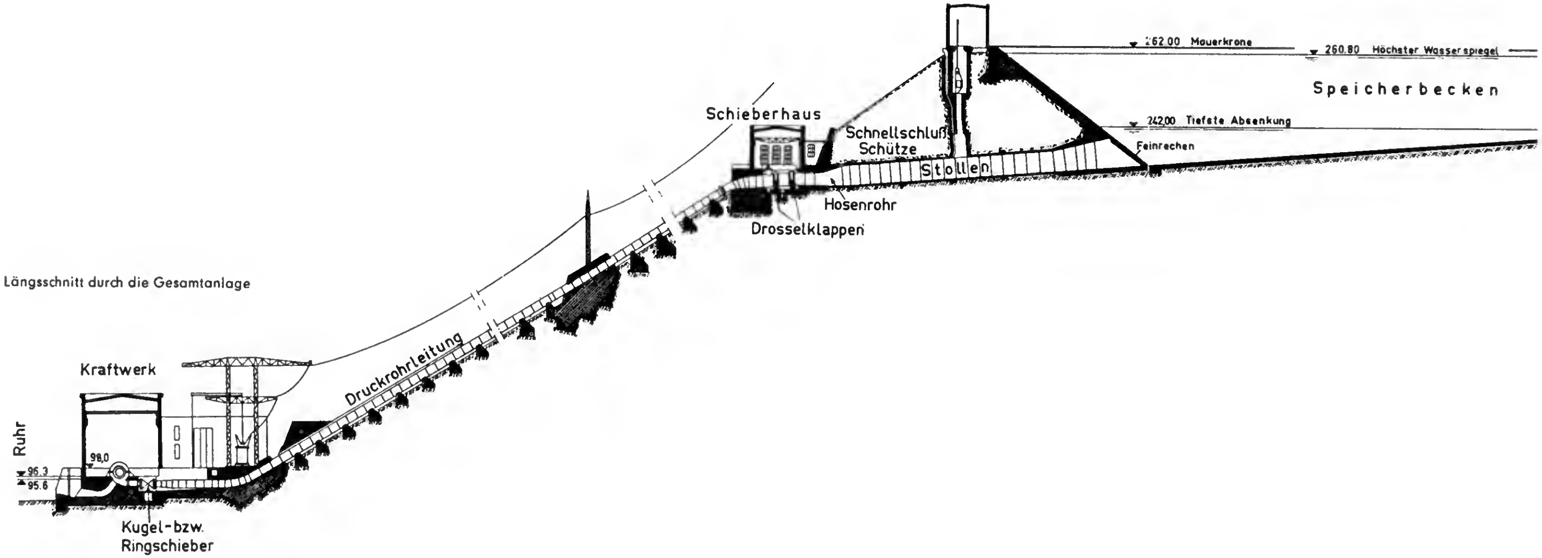
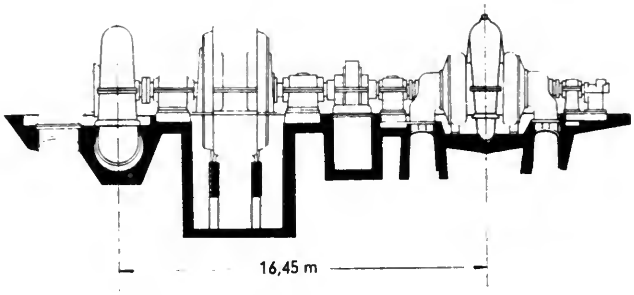
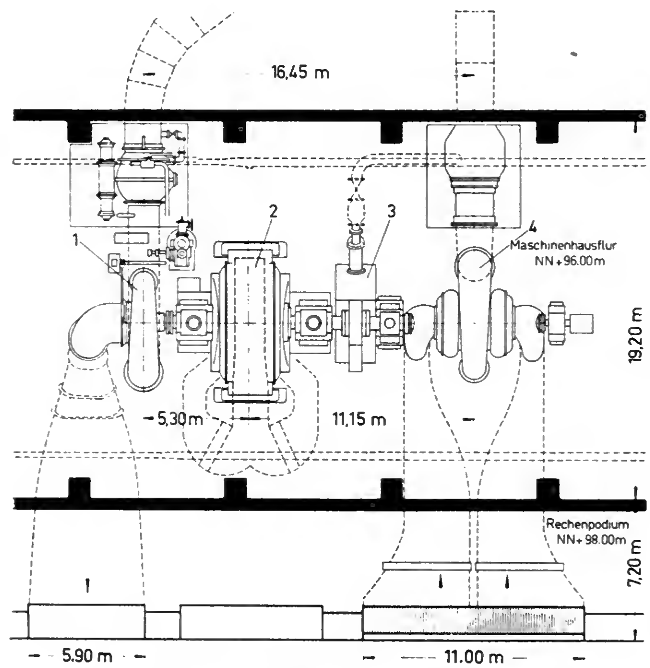



Fig. 19.3 - Profile of System.




Aufriß eines Maschinensatzes

Fig. 19. 4 - Elevation of Pump and Turbine




Stauziel NN+ 96,30 m
Absenkziel NN+ 95,60 m

Fig. 19. 5 - Plan view of Pump and Turbine

Fig. 19.6 - Seal Ring of Spherical Valve

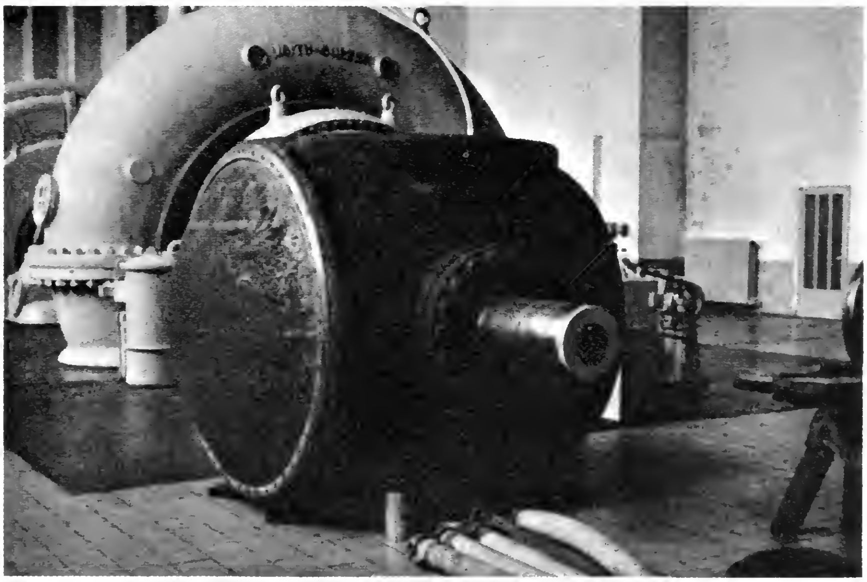


Fig. 19.7 - Rotating Member of Spherical Valve

Fig. 19.8 - Casing Wear Ring

Fig. 19.9 - Impeller Wear Ring

Fig. 19.10 - Replaced Impeller

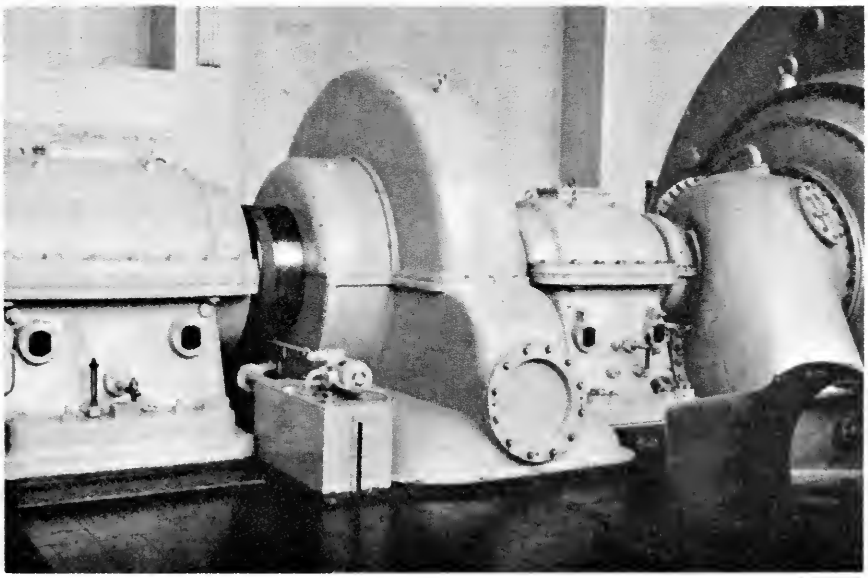


Fig. 19.11 - Starting Turbine

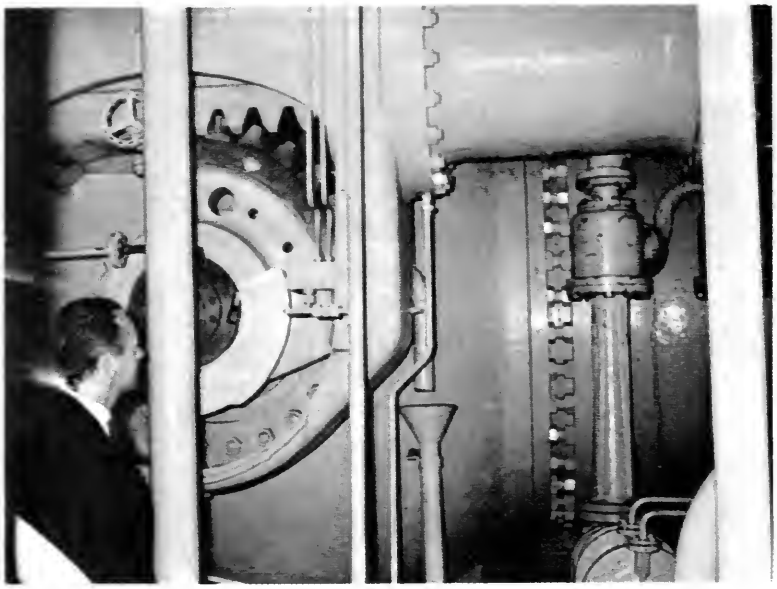


Fig. 19.12 - Valve Operating Mechanism

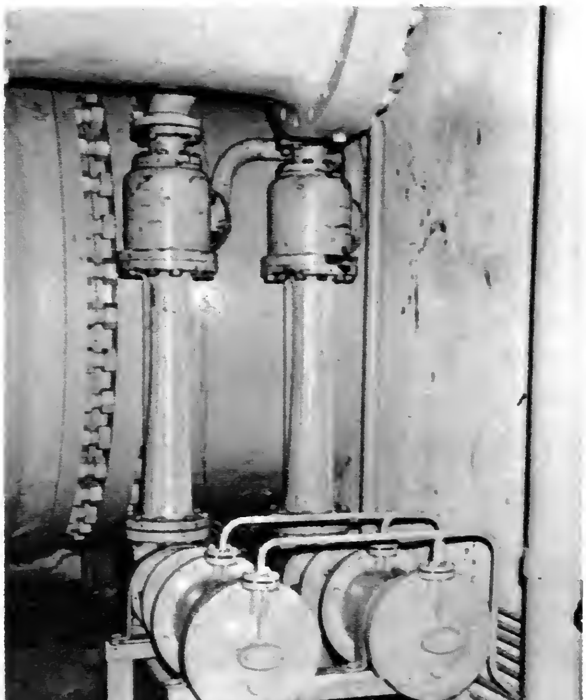


Fig. 19.13 - Valve Operating Mechanism and Dewatering Ejectors

## Vibration Records

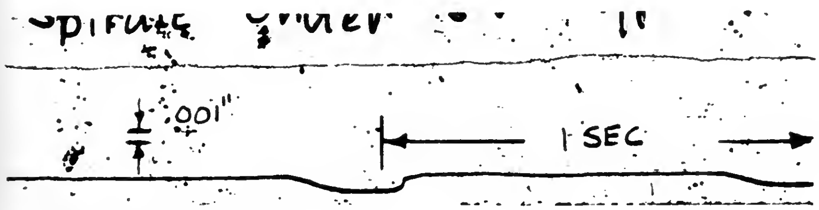
Rheinisch - Westfälisches Elektrizitätswerk AG,
Essen, Germany

Plant : Herdecke (surface power house)

Units : four, 2-stage, double flow, horizontal pumps;
33,000 HP, 494 cfs, 509 ft, 300 RPM

Records-taken : August 4, 1964

Unit 3 - During Starting Process
(discharge valve closed)




1. Spiral casing

2. Spiral casing


3. Bearing, coupling side, transverse direction

4. Bearing, coupling side, transverse direction

| Record | Frequency c.p.m. | Average Amplitude inches |
|---|---|---|
| 1. Spiral casing | ---- | .0002 |
| 2. Spiral casing | ---- | less than .0002 |
| 3. Bearing, coupling side, transverse direction | 4800 | .0002 |
| 4. Bearing, coupling side, transverse direction | ---- | less than .0002 |

Figure 19-14

PLANT NAME: VIANDEN

REPORT NO.: 20

| | |
|---|---|
| LOCATION-ALTITUDE: | Vianden . Northern Luxemburg - 680' |
| OWNER: | Societe Electrique De l'Our |
| ADDRESS: | Luxemburg, Luxemburg |
| TYPE OF PLANT: | Underground - Pump Storage - Generating |
| SERVICE | Furnish power to Network |
| TYPE OF WATER: | Clean and Clear |
| UNITS INSTALLED: | Nine Horizontal two-stage, double suction pumps - Pelton Turbine - Generators |
| HORSEPOWER: | 9 x (90, 900 - 92, 800) 428.6 RPM |
| CFS: | 9 x ( 733 - 804 ) |
| STATIC HEAD: | 995' |
| PLANT STARTED: | I - 10/62; II - 11/62; III - 1/63; IV - 4/63; V - 11/63<br>VI - 2/64; VII - 6/64; VIII - 12/63; IX - 3/64 |
| VISITED BY: | Hartmann - Westman - Gartmann |
| DATE: | Aug. 4, 1964 (Cole - June 29, 1964) |
| PERSON(S) INTERVIEWED & TITLE(S): | A. Kass, Director<br>L. Wehenkel, Asst. to Director<br>Mosca (Escher Wyss) |
| REMARKS: | Nine horizontal units in underground cavern 15 MTS x 15 MTS x 320 MTS (49.25' x 49.25' x 1050') |

## PUMPS:

TYPE: Horizontal - 2-stage, double suction

MANUFACTURER: I, III, VIII, IX - Voith
II, IV, V, VI, VII - Escher Wyss

SIZE DISCHARGE: 71" (Escher Wyss)

SIZE SUCTION: E-W = 2 x 57" - Voith; 2 x (51. 2" x 90. 5 Oval)

RPM: 428. 6

CFS: 733 - 802

HEAD: 960 - 880

H.P. REQUIRED: 88, 500 - 89, 000

N s.: 1695 - 1900

INSTALLED: Two in 1962, four in 1963, three in 1964

| HRS. OF OPERATION | I | II | III | IV | V | VI | VII | VIII | IX |
|---|---|---|---|---|---|---|---|---|---|
| Turbine | 2535 | 2820 | 2386 | 3387 | 669 | 414 | 105 | 519 | 386 |
| Pump | 3616 | 4570 | 3255 | 2605 | 1308 | 771 | 151 | 1145 | 753 |
| Condenser | 3996 | 5202 | 4183 | 3942 | 2252 | 1360 | 285 | 2152 | 1199 |

MIN. SUBMERGENCE: 41. 8'

NORMAL SUBMERGENCE: -

MAX. SUBMERGENCE: 66. 6'

REMARKS: Minimum submergence often occurs.

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | No Model |
| MODEL ACTUAL: | " " |
| PROTOTYPE-GUARANTEED: | 88.5 E-W; 91 Voith |
| PROTOTYPE-ACTUAL: | 90 - 91 |
| METHOD OF TEST: | Thermodynamic Method |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 71" |
| DIAMETER IMPELLER: | E-W - 94"; Voith - 93" |
| DIAMETER EYE: | E-W = 27.4" - 54.75"; Voith 1st stage 28.7"-60"<br>2nd " 31.5"-60" |
| DIAMETER SHAFT: | E-W: 27.4"; Voith: 25.6" - 30"<br>Voith Impellers bolted to shaft flange - E-W keyed |
| MATERIAL CASING: | Cast Steel (Volute-welded steel) |
| MATERIAL IMPELLER: | 1st stage 13% Cr. -2nd Stage Cast steel |
| MATERIAL IMPELLER RINGS: | Steel (Dia. 65" - 66" - 68" |
| MATERIAL-CASING RINGS: | Bronze |
| RADIAL CLEARANCE: | 0.970 - 0.800 mm |
| MATERIAL BALANCING RINGS: | None |
| MATERIAL INTERSTAGE SEAL: | Babbitt against shaft |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | Unknown |
| BEARING: | 22.4" - Babbitt |
| THRUST BEARING: | Kingsbury-type - Each side of O.B. bearing |

| | |
|---|---|
| TYPE OF PACKING: | Mechanical Seal - E-W Split; Voith No. |
| MATERIAL OF PACKING: | Carbon rings |
| MATERIAL OF SLEEVE: | Bronze |
| CLEARANCE: | - |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Horizontal - Synchronous |
| MANUFACTURER: | I, III, VIII, IX- Siemens; II, V* ACEG; IV, VI, VII** AEG |
| H. P. | 94, 000 |
| RPM: | 428. 6 |
| VOLTAGE: | 13. 8 kv |
| STARTING: | By small Pelton turbine with pump unwatered. |

REMARKS: Pump on one end - Turbine on other -
*ACEG = Ateliers Constructions Electriques de Charlrois (Belgium)
*AEG = Allgemein Elektrisch Gesellschaft (Germany)

TURBINE:

| | |
|---|---|
| TYPE: | Francis |
| MFG: | I, III- Neyrpic; VII, IX Voith; Rest are Escher-Wyss |
| HEAD: | 950' |
| RPM: | 428. 6 |
| H. P.: | 143, 000 |
| REMARKS: | Gear coupling between pump and motor. |

## VALVES:

### INTAKE:

| | |
|---|---|
| TYPE: | Gates |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | Used for dismantling pump only |

### DISCHARGE:

| | | |
|---|---|---|
| TYPE: | I - IV - Needle | V - IX - Spherical |
| MANUFACTURER: | Voith | Escher-Wyss |
| SIZE: | 71" (1800 mm) | 71" (1800 mm) |
| OPERATION: | | |
| OPENING: | Oil Pressure | |
| CLOSING: | Water Pressure | |
| TIME OF CLOSING: | | |
| NORMAL: | - | |
| EMERGENCY: | - | |
| REMARKS: | Spherical valves have rubber seals on "repair" side, stainless steel on working side. | |

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | 2 x 19.65' (for 4 units) - 2 x 21.3' (for 5 units) |
| LENGTH: | 1570' - 2225' |

| | |
|---|---|
| MATERIAL: | - |
| TYPE OF UPPER GATE: | Sliding gate in intake tower |
| SURGE TANK: | None |
| REMARKS: | |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Relatively clean |
| Ph: | - |
| HARDNESS: | Soft |
| REMARKS: | Contains $CO_2$ |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | - |
| STARTS/DAY: | As needed - Probably once/day |
| HOURS OF OPERATION: | See second page |
| UNPLANNED OUTAGES: | None |
| CAUSE: | - |
| INSPECTION SCHEDULE: | None scheduled |
| TIME REQUIRED: | 4 hours |
| OVERHAUL SCHEDULE: | 3 or 4 years planned |
| TIME REQUIRED: | 250 M-H for disassembly - 450 for assembly |
| IMPELLER CAVITATION: | A little in Voith - improved by reworking valves. Guarantee calls for 3000 hrs. without cavitation damage. |

| | |
|---|---|
| SEAL RING WEAR: | None |
| NOISE LEVEL-START: | 105 - 115 |
| NOISE LEVEL-RUN: | 98 |
| VIBRATION: | None |
| REMARKS: | Only one pump inspected so far. In case of Penstock break, upper gates close. Drain of Penstock will not fill station. Gates on suction line can be closed above water level. |

## GENERAL REMARKS

The power house lies in a cavern between upper and lower reservoir; the necessary connections to the upper and lower reservoir are established by two pressure shafts and tail water tunnels lying in the rock. A cavern was given preference for the following reasons: the Our valley is exceptionally narrow and does not allow the erection of an open power house the total length of which reaches 300 m. Moreover, the location in the mountain allows the shortest connection to upper and lower reservoir, whereby a good hydraulic efficiency and favorable regulating conditions for the machines are ensured.

The longitudinal section shows the location of the power plant between upper and lower reservoir, and its arrangement in the mountain-crest which consists of very hard slate rock, being quite dry in spite of clefts. Though the rock quality is good, the whole pressure shaft is armoured in order to ensure a high service reliability under all conditions. The intake tower of the first basin may be closed by a cylindrical valve. The terrain section through the cavern shows that the whole plant and tunneling system was well fitted into the mountain and that it is roofed over by a strong layer of rock. The distributing pipe-line is disposed upstream. In the center we find the large cavern excavation with a height of about 30 m and a width of about 20 m. Downstream the two tail water channels are located, each of them having to carry up to 160 cu. m. / s. of water during turbine operation. The tunnel for the housing of the transformers and for the tail water locking devises are also to be found there.

The ground plan of the machine hall shows that each of the 9 horizontal machine groups consists of one turbine, one motor-generator, and one pump. A clutch (starting turbine with toothed-rim clutch) allows engagement and disengagement at standstill and during operation. When choosing this arrangement one has to take into consideration that a rapid starting-up of the plant and a quick change from turbine to pump operation and vice versa are possible. According to the experience gathered in pumped storage plants up to now, the machine groups are used for the production of reactive power without extra cost during the time that turbines and pumps are not in operation. The average water flow of a turbine lies at 39 cu. m. / s. and the delivery rate of a pump at 21 cu. m. / s. The maximum pumping capacity amounts to 94, 000 h. p.

The daily oscillation in quantity of water between upper and lower reservoir amounts to about 2.4 million cu.m. in the first stage of development at 4-1/4 hours of utilization. The upper and lower reservoir were designed for a large useful volume, in order to have the necessary reserve during low water periods and at times of ice formation. Moreover, during week-ends it is possible to pump for a longer time. The pumping time at night amounts to about 8 hours.

The short periods for starting-up the plant are remarkable. It takes only 140 seconds to build up peak loads from standstill, and 80 or 70 seconds for switching over from turbine to pump operation and vice versa.

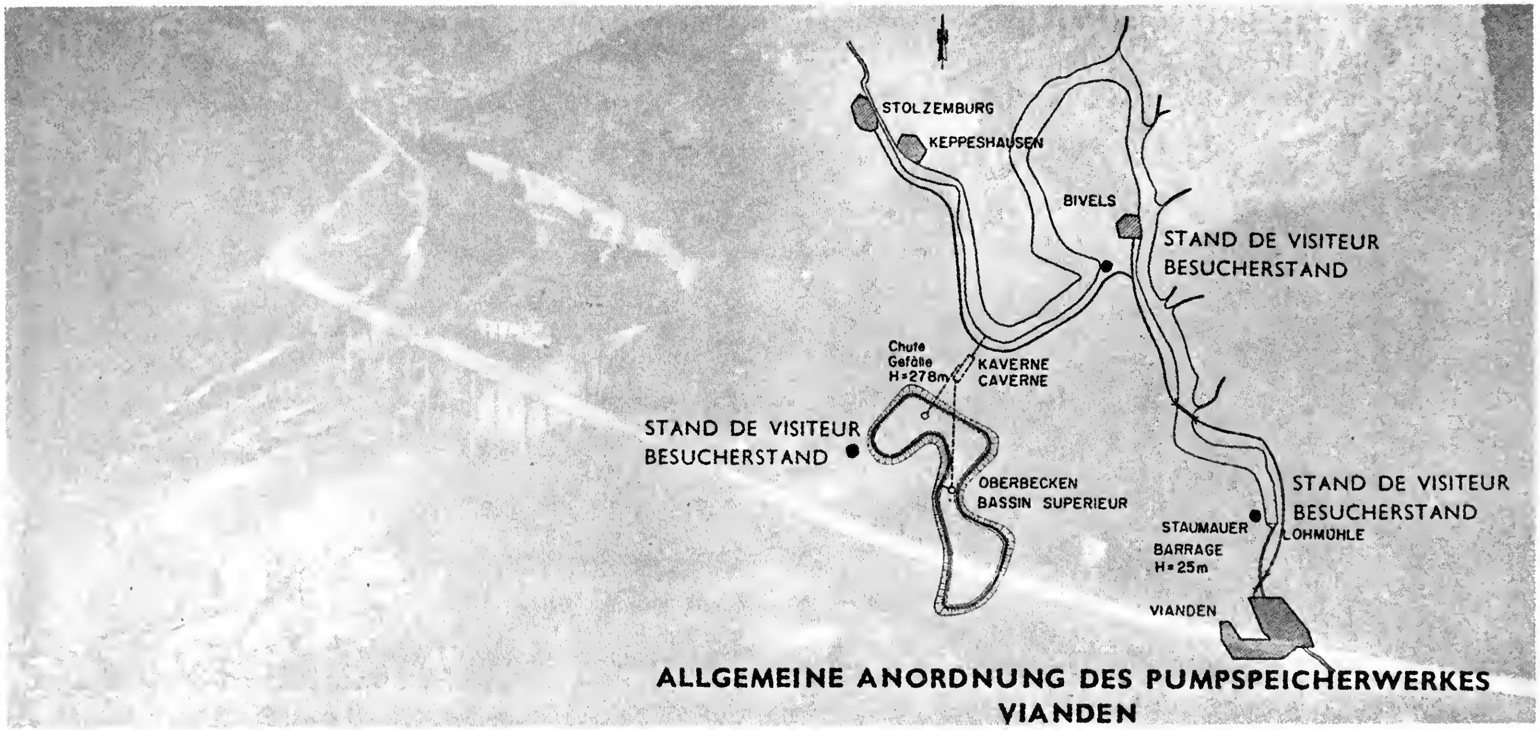



Fig. 20-1 - General arrangement of Vianden Pumping System

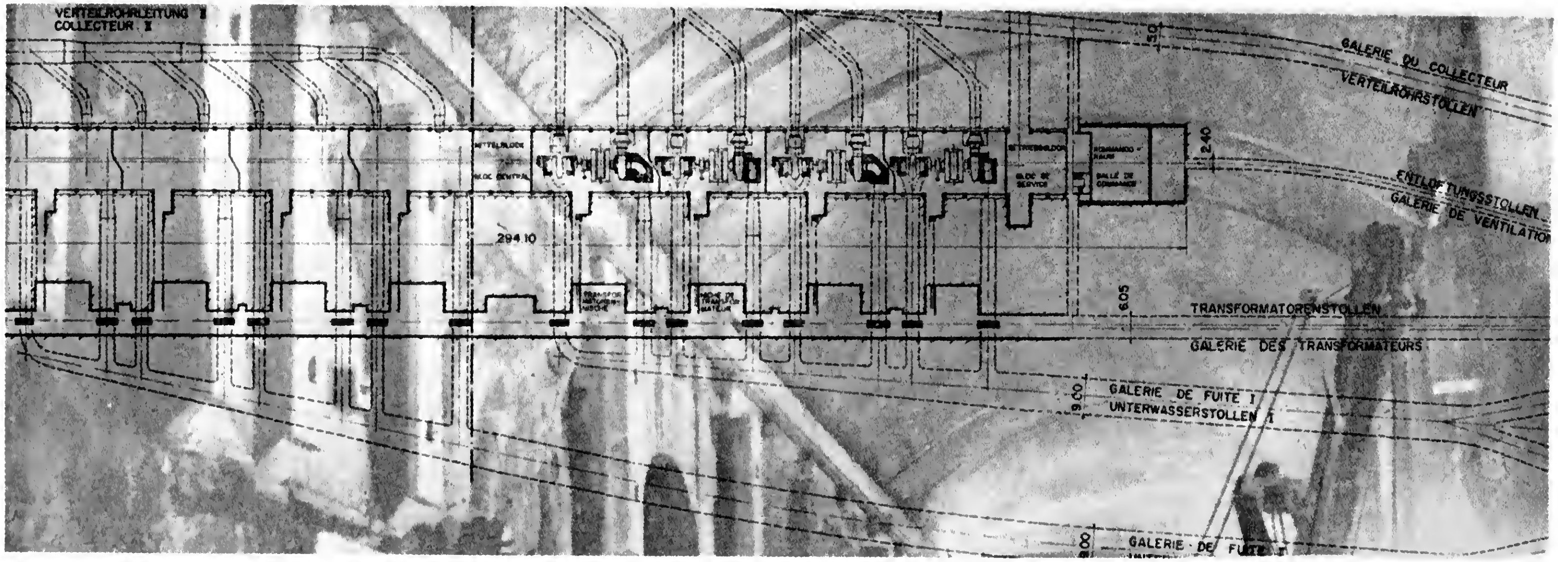



Fig. 20-2 - Plan of Pump Station and Tunnel System


Fig. 20-3 - Cross Section through Turbine (right) and Pump (left)

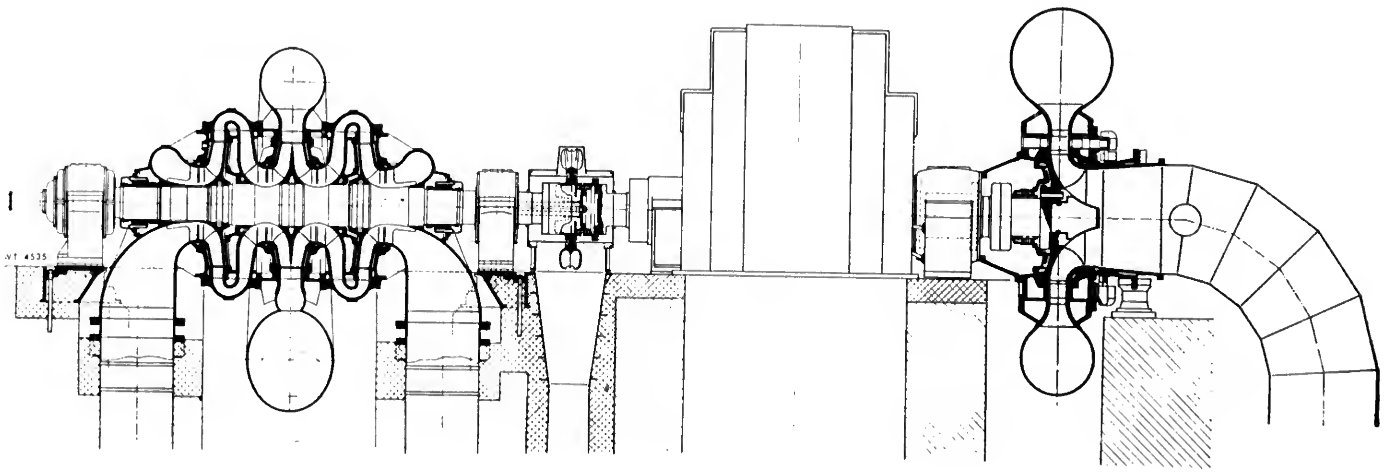


Fig. 20. 4 - Cross Section of Pump and Turbine

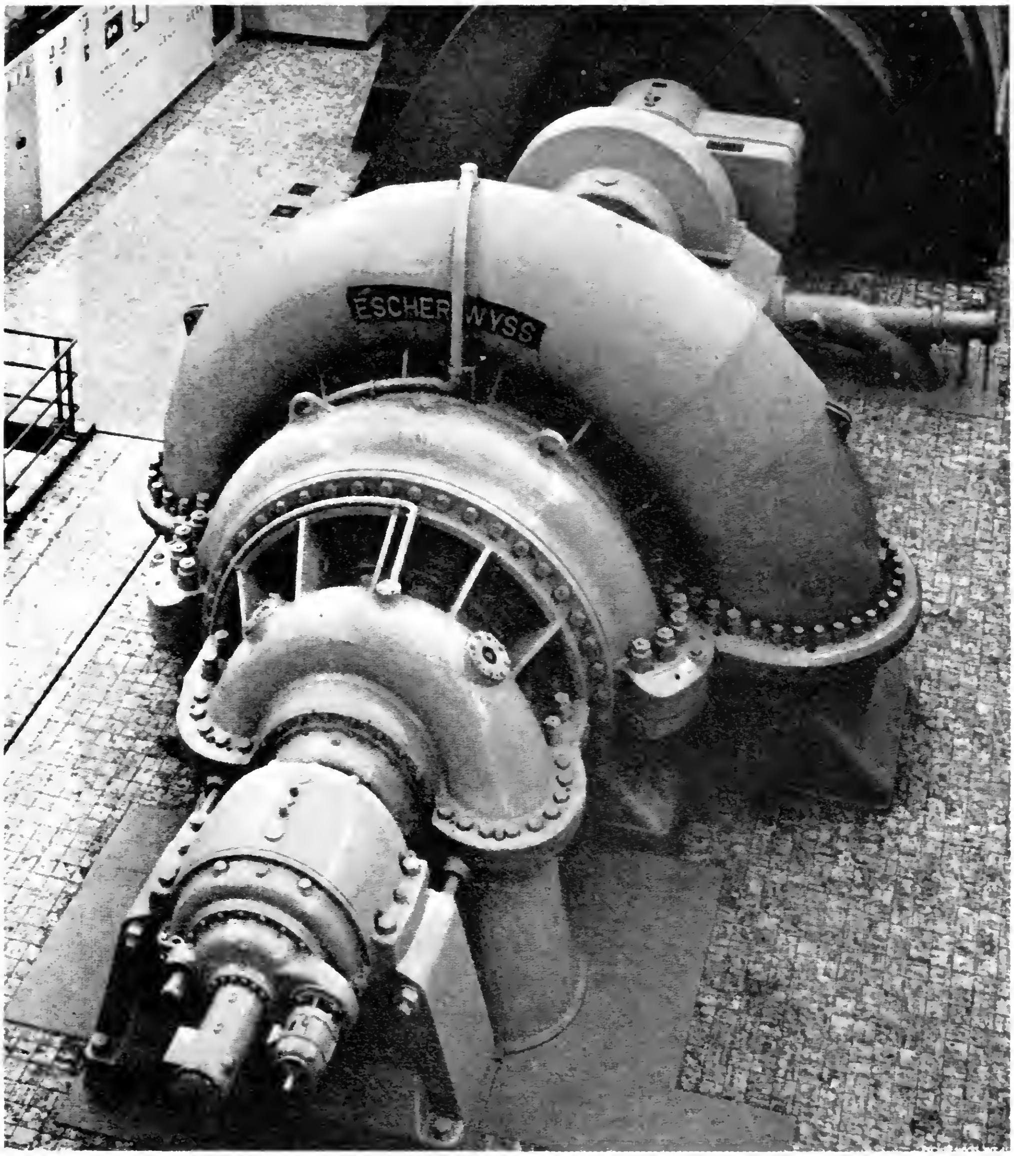



Fig. 20.5 - View of Escher Wyss Pump

Fig. 20.6 - Interior of Plant

Fig. 20.7 - View of Second Stage Impeller

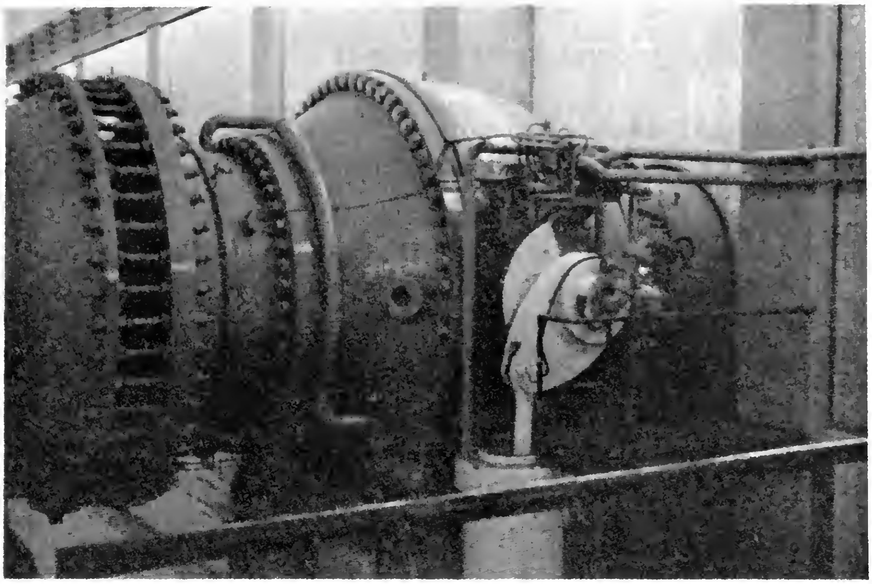


Fig. 20.8 - Expansion Joint and Turbine Inlet Valve

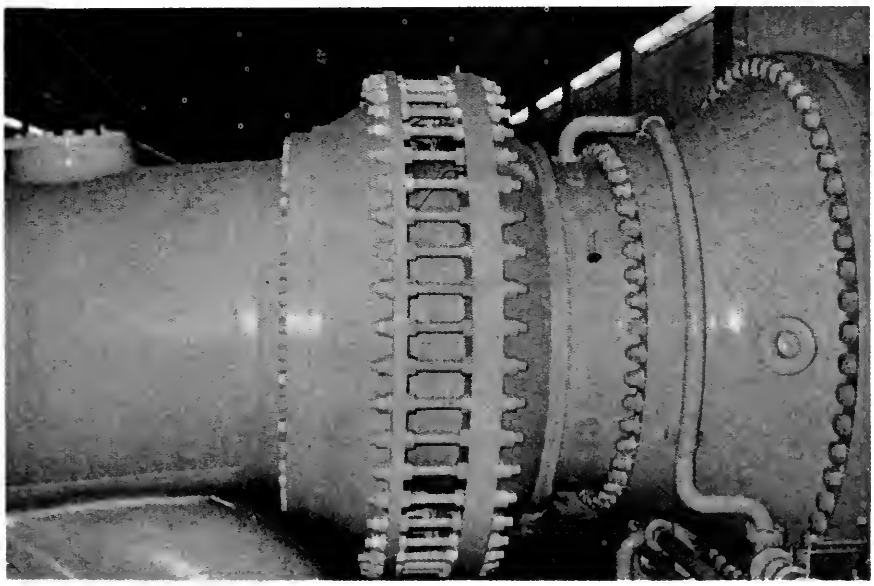


Fig. 20.9 - Expansion Joint

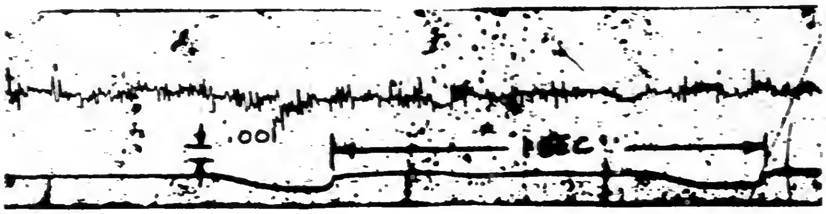
## Vibration Records

Société Electrique de l'Our SA, Luxemburg, Luxemburg

Plant : Vianden (underground power house)

Units : nine, 2-stage, double flow, horizontal pumps; 92,800 HP, 803 cfs, 879 ft, 428.6 RPM

Records-taken : August 5, 1964




1. Turbine #1, inlet casing

2. Turbine #2, inlet casing

3. Turbine #3, inlet casing

| | Frequency c.p.m. | Average Amplitude inches |
|---|---|---|
| 1. | 6000 | .0009 |
| 2. | 6600 | .0003 |
| 3. | 7800 | .0040 |

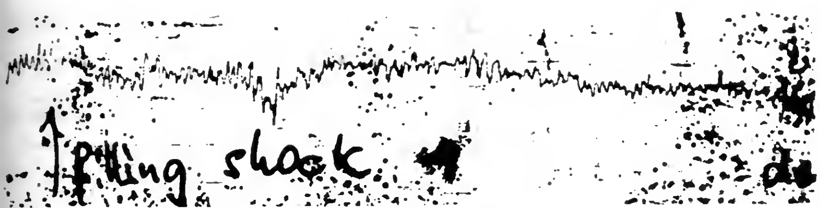
Figure 20-10

## Vibration Records (cont.)

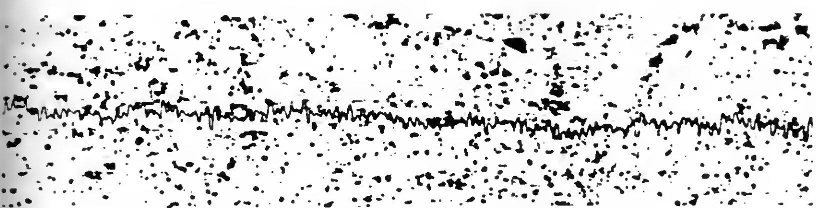
Sociētē Electrique de l'Our SA, Luxemburg, Luxemburg

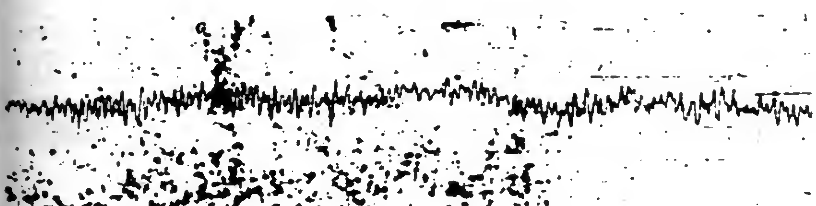
Plant : Vianden (underground power house)

Starting Pump #6



4. Volute - filling shock


5. Volute - de-aeriation period


6. Volute - discharge valve opening

| Record | Frequency / c.p.m. | Average Amplitude inches |
|---|---|---|
| 4 | 9600 | .0020 |
| 5 | 5400 | .0010 |
| 6 | 7200<br>4200 | .0003 to<br>.0020 |

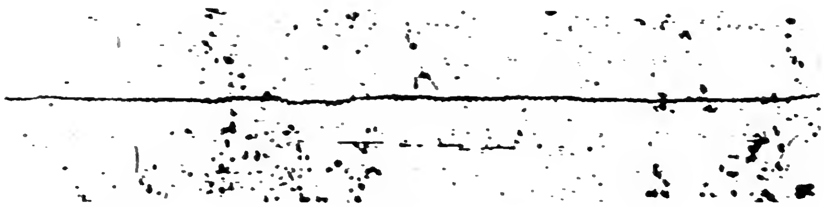
Figure 20-11

## Vibration Records (cont.)

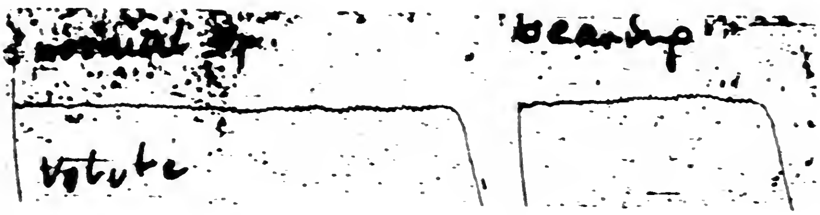
Société Electrique de l'Our SA, Luxemburg, Luxemburg

Plant : Vianden (underground power house)

Pump #6



7. Volute - discharge valve open




8. Volute - normal pump operation
9. Bearing - normal pump operation

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 3900 | .0004 |
| 11,000 | .0002 |
| 12,000 | less than .0002 |
| 4800 | .0003 |

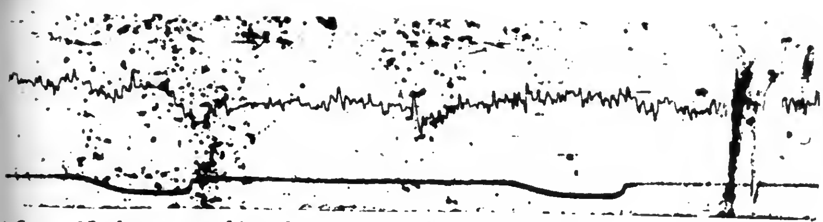
Figure 20-12

## Vibration Records (cont.)

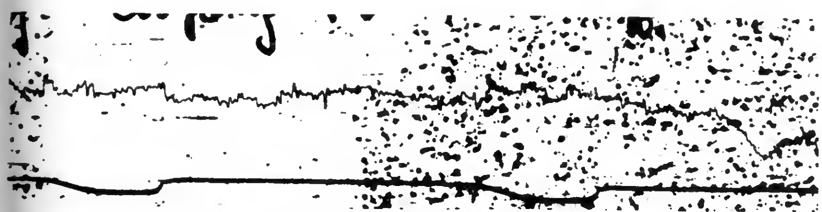
Sociētē Electrique de l'Our SA, Luxemburg, Luxemburg

Plant : Vianden (underground power house)

Pump #6



10. Volute - discharge valve closing



11. Bearing, coupling side-dewatering pump

12. Bearing, coupling side-pump dewatered

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 6000 | .0013 |
| 6000 | .0010 |
| ---- | .0002 |

Figure 20-13

PLANT NAME: VILLA GARGNANO

REPORT NO.: 21

| | |
|---|---|
| LOCATION-ALTITUDE: | West Shore of Lake Garda, Italy - 154' |
| OWNER: | E. N. E. L. - Ente Nazionale per l'Energia |
| ADDRESS: | Elettrica (formerly S. E. L. T. Valdarno) |
| TYPE OF PLANT: | Underground |
| SERVICE | Pump storage - Generation for Italian Network |
| TYPE OF WATER: | Pure Lake Water |
| UNITS INSTALLED: | Two vertical - double-suction pumps - Motor-Generator - Turbine sets |
| HORSEPOWER: | 85,000 (600 RPM) |
| CFS: | 487 |
| STATIC HEAD: | 1380 |
| PLANT STARTED: | March 1964 |
| VISITED BY: | Gartmann - Hartmann |
| DATE: | 1964 August, 18th - 19th |
| PERSON(S) INTERVIEWED & TITLE(S): | Elio Giaccheri (ENEL)<br>Antonio Reghelin<br>Giacoma Dal Cajon |
| REMARKS: | Plant interior 98.5' x 32.5'. Motors placed above high water level of lake. Access tunnel 443'. |

## PUMPS:

TYPE: Vertical - Two-stage, double-suction

MANUFACTURER: Escher-Wyss

SIZE DISCHARGE: 55"

SIZE SUCTION: 2 x 47.2"

RPM: 600

| | I | | | II | | |
|---|---|---|---|---|---|---|
| CFS: | 430 | 496 | 575 | 424 | 487.5 | 565 |
| HEAD: | 1440 | 1365 | 1260 | 1453 | 1400 | 1275 |
| H.P. REQUIRED: | 79,000 | 85,000 | 88,000 | 77,000 | 85,000 | 88,000 |

N s.: 1479

INSTALLED: March 1964

HRS. OF OPERATION 640 to 1170

MIN. SUBMERGENCE: 47.0'

NORMAL SUBMERGENCE: 52.0'

MAX. SUBMERGENCE: 62.0'

REMARKS: Reverse speed 750 Max.

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | - |
| PROTOTYPE-GUARANTEED: | 91.1 |
| PROTOTYPE-ACTUAL: | - |
| METHOD OF TEST: | - |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 55" |
| DIAMETER IMPELLER: | 78.5" (1990 mm) |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 23.6" (600 mm) |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: 1) | Stainless steel |
| MATERIAL IMPELLER RINGS: | Stainless steel |
| MATERIAL-CASING RINGS: | Stainless Steel |
| RADIAL CLEARANCE: | - |
| MATERIAL BALANCING RINGS: | None |
| MATERIAL INTERSTAGE SEAL: | Babbitt |
| RADIAL CLEARANCE: | .75 - .82 mm |
| MATERIAL DIFFUSER: | Stainless Steel |
| BEARING: | Babbitt |
| THRUST BEARING: | Michell type at bottom. |

1) Impeller shrunk on - 1% Cone, 200 ATM. pressure. Shaft sleeve shrunk on.

| | |
|---|---|
| TYPE OF PACKING: | Labyrinth |
| MATERIAL OF PACKING: | Stainless Steel |
| MATERIAL OF SLEEVE: | Stainless Steel |
| CLEARANCE: (Radial) | .35 - .45 mm |
| REMARKS: | Short Babbitt bushing outboard. |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical - Synchronous |
| MANUFACTURER: | CGE |
| H. P.: | - |
| R. P. M.: | 600 |
| VOLTAGE: | 10,000 |
| STARTING: | By turbine |
| REMARKS: | - |

TURBINE:

| | |
|---|---|
| TYPE: | Vertical |
| MFG.: | Escher Wyss |
| HEAD: | 1350' ± |
| R. P. M.: | 600 |
| H. P.: | - |
| REMARKS: | Turbine dewatered when pumping. |

## VALVES:

### INTAKE:

| | |
|---|---|
| TYPE: | Butterfly (one) |
| MANUFACTURER: | Escher-Wyss |
| SIZE: | 71" |
| OPERATION: | Oil - Hydraulic |

### DISCHARGE:

| | |
|---|---|
| TYPE: | Needle double seated |
| MANUFACTURER: | Von Roll |
| SIZE: | 55" |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | 250 mm dia. Bypass Valve. |

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | 1 x 8.375' |
| LENGTH: | 1585' at 50° from horizontal, then into circular tunnel, 13.8' dia., 17,350' long with 3% slope. |

| | |
|---|---|
| MATERIAL: | Reinforced concrete |
| TYPE OF UPPER GATE: | Sliding gate 9' x 13.8' |
| SURGE TANK: | One at each end of tunnel |
| REMARKS: | Inlet tunnel 1075' long - 13.1' dia. |

| | |
|---|---|
| WATER QUALITY: | Excellent |
| GENERAL: | Clear cool lake water |
| Ph: | - |
| HARDNESS: | Soft |
| REMARKS: | - |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | Approximately 10 hrs. |
| STARTS/DAY: | Once |
| HOURS OF OPERATION: | 640 to 1170 |
| UNPLANNED OUTAGES: | - |
| CAUSE: | - |
| INSPECTION SCHEDULE: | Not organized |
| TIME REQUIRED: | " " |
| OVERHAUL SCHEDULE: | " " |
| TIME REQUIRED: | - |
| IMPELLER CAVITATION: | Yes - 1st stage |

| | |
|---|---|
| SEAL RING WEAR: | - |
| NOISE LEVEL-START: | 115 |
| NOISE LEVEL-RUN: | 108 - 110 |
| VIBRATION: | Change over - .003 - Run - .0008 |
| REMARKS: | Pump noisy, especially against closed valve. Much electrical trouble. |

## GENERAL REMARKS

Villa Gargnano is a recently installed pump storage plant, located on Lake Garda in Northern Italy. The two units, each consisting of a vertical motor-generator, a single-stage Francis turbine, an automatic gear coupling, and a two-stage double-flow pump, are installed in an underground plant, and are rated at 85,000 H. P. at 600 RPM, when pumping. The pumps take water from the lake through a tunnel, approximately 1000 ft. long, the lake level being at elevation 210 minimum to 216' maximum, and the center line of the pump being at elevation 154 ft.

The pumps have operated approximately 1000 hrs. and, therefore, no inspection has been made of the interior parts since the start-up.

The pumps are extremely noisy, and indications are that both first-stage impellers are cavitating.

The pumps were built in Italy by the Italian branch of Escher-Wyss. At the time of the visit they had not as yet been accepted by the Utility.

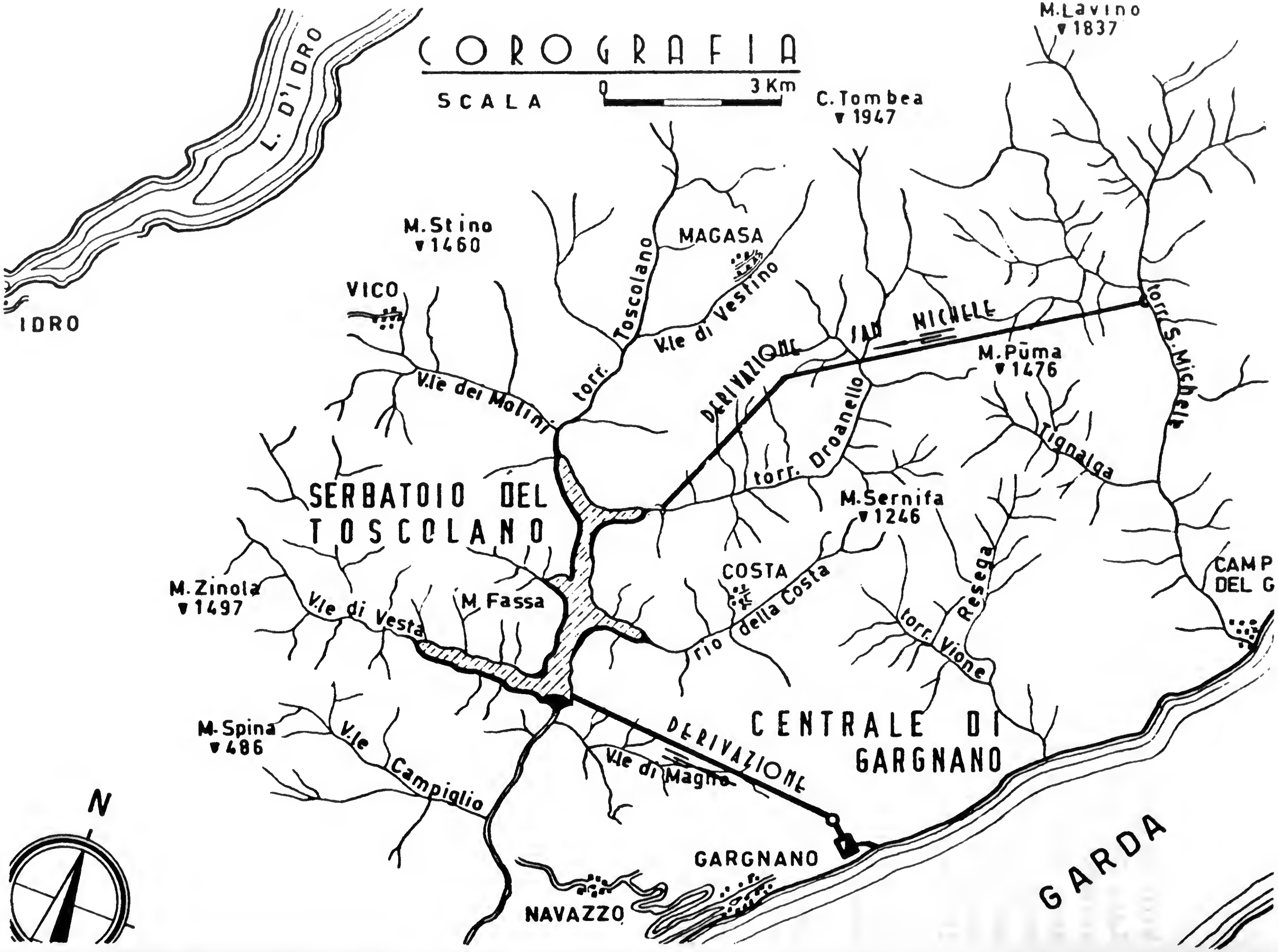



Fig. 21.1 - Area Map

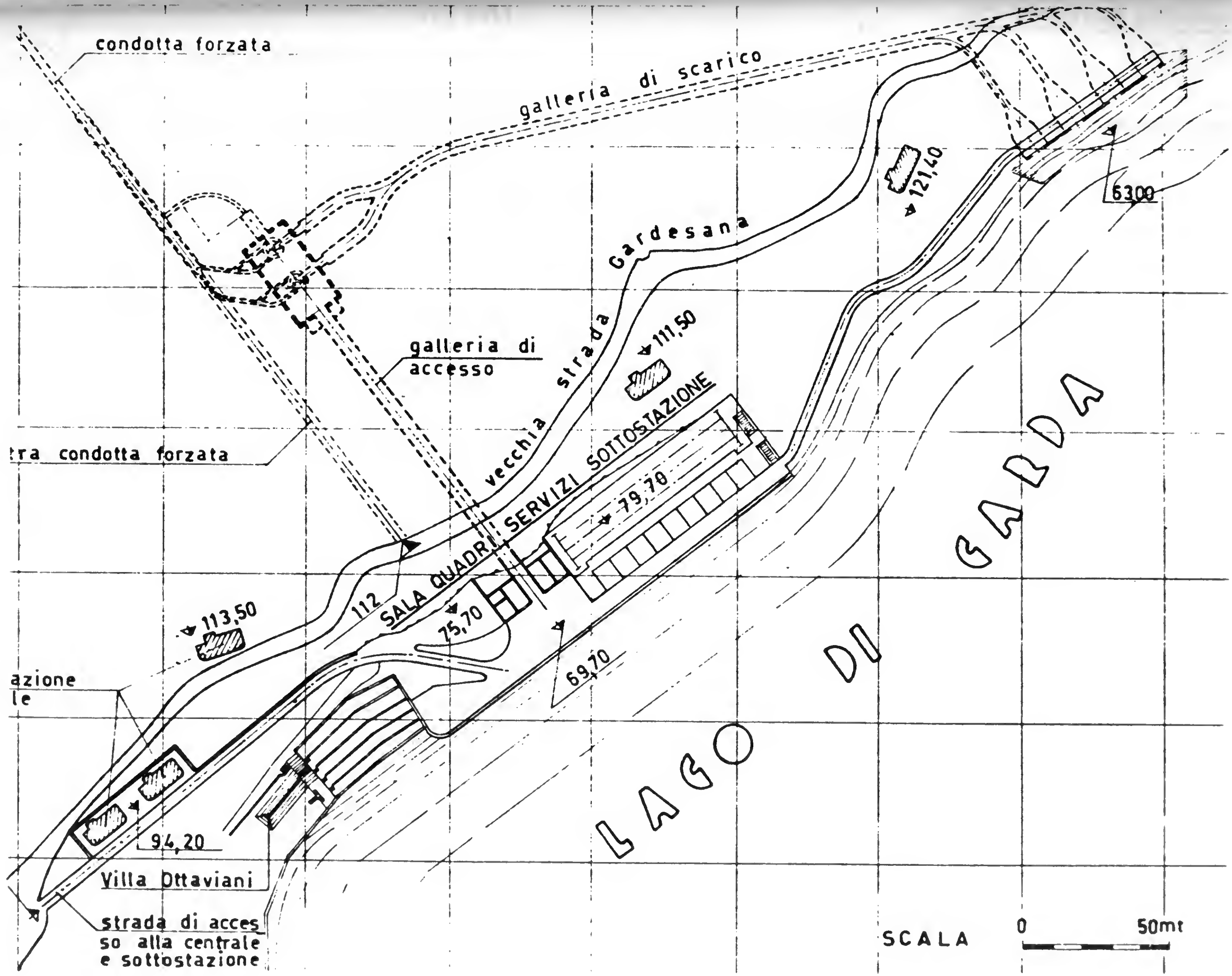



Fig. 21.2 - Station Location

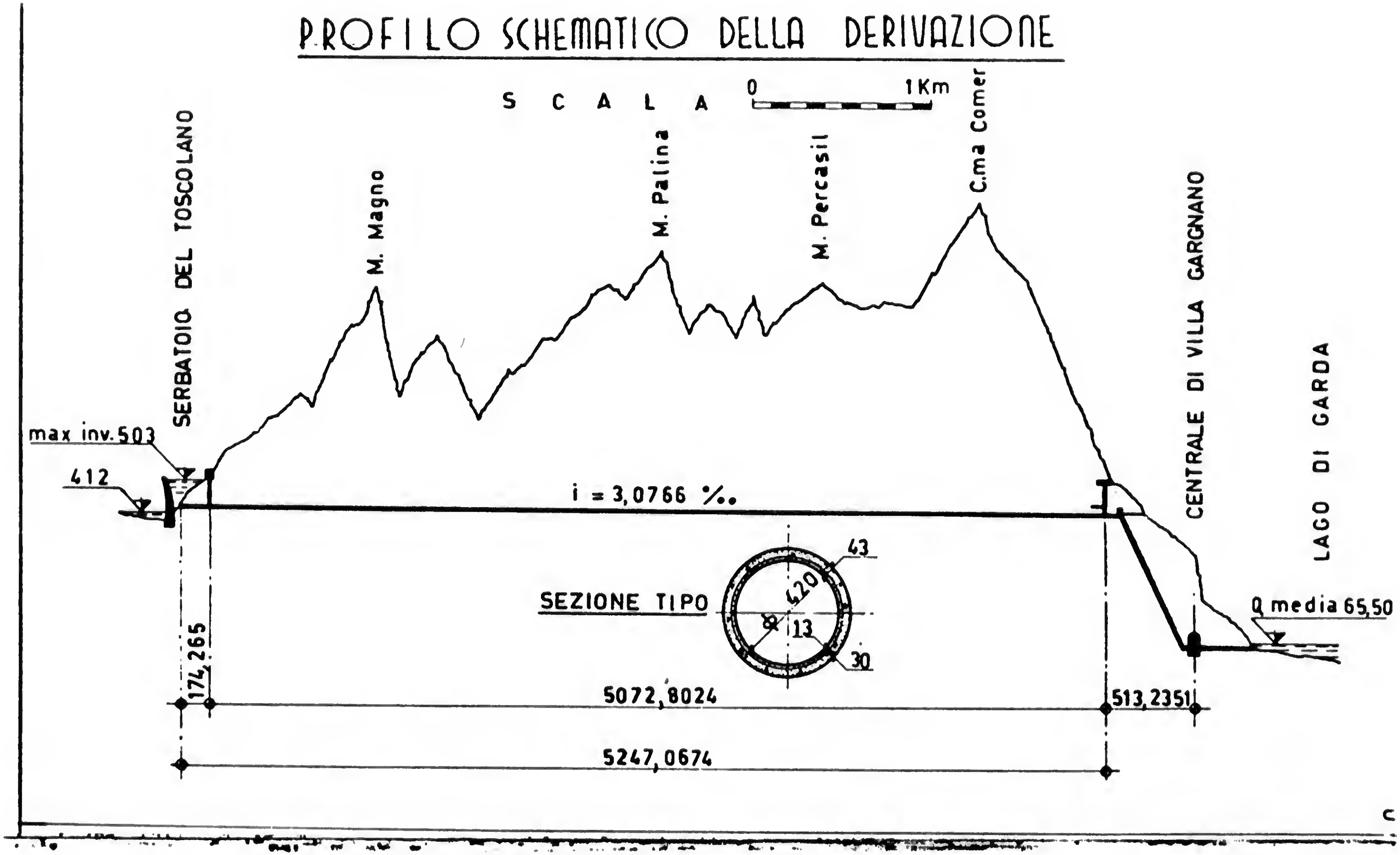



Fig. 21. 3 - Profile of System

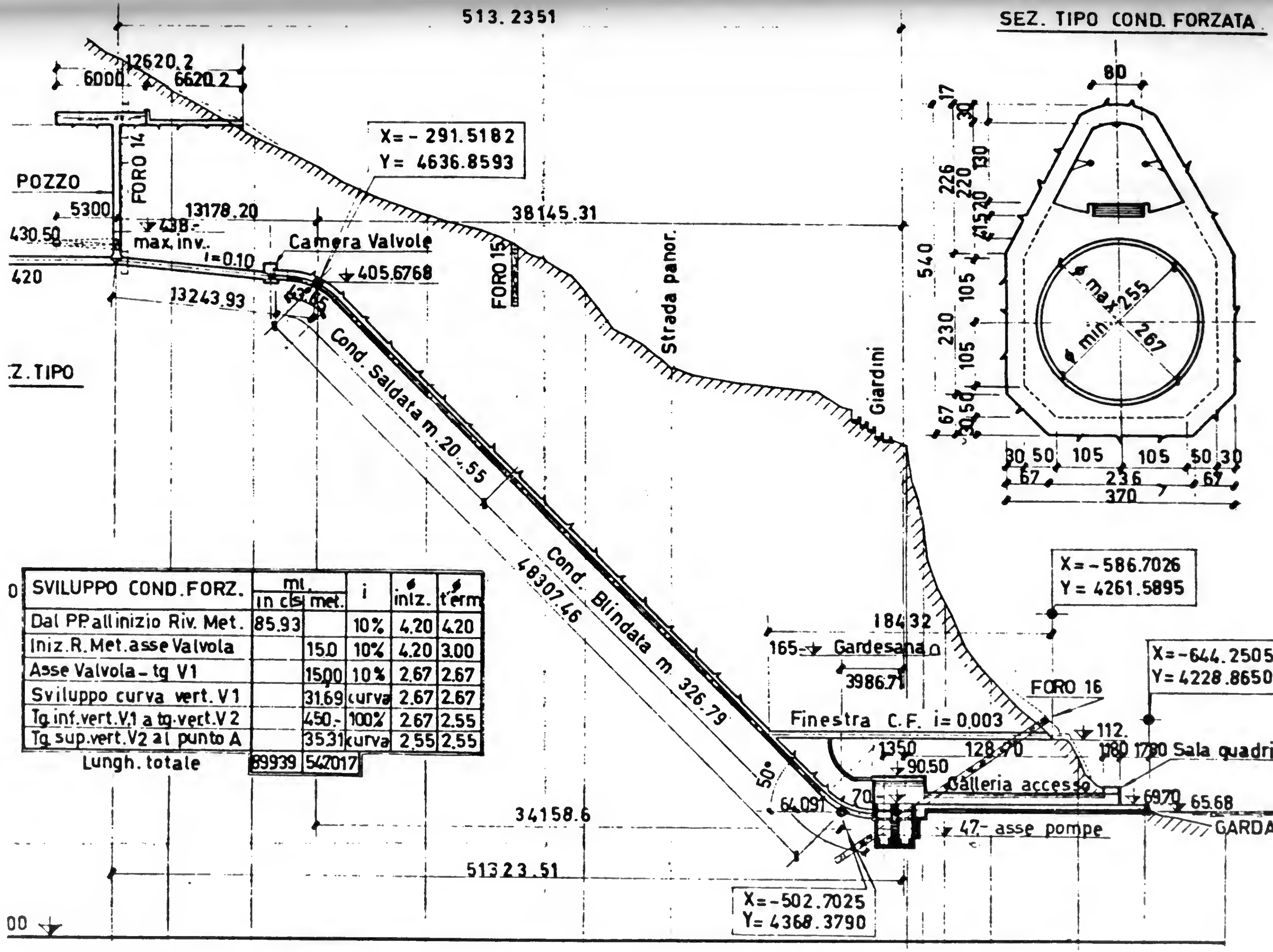



Fig. 21.4 - Discharge Penstock and Surge Chamber

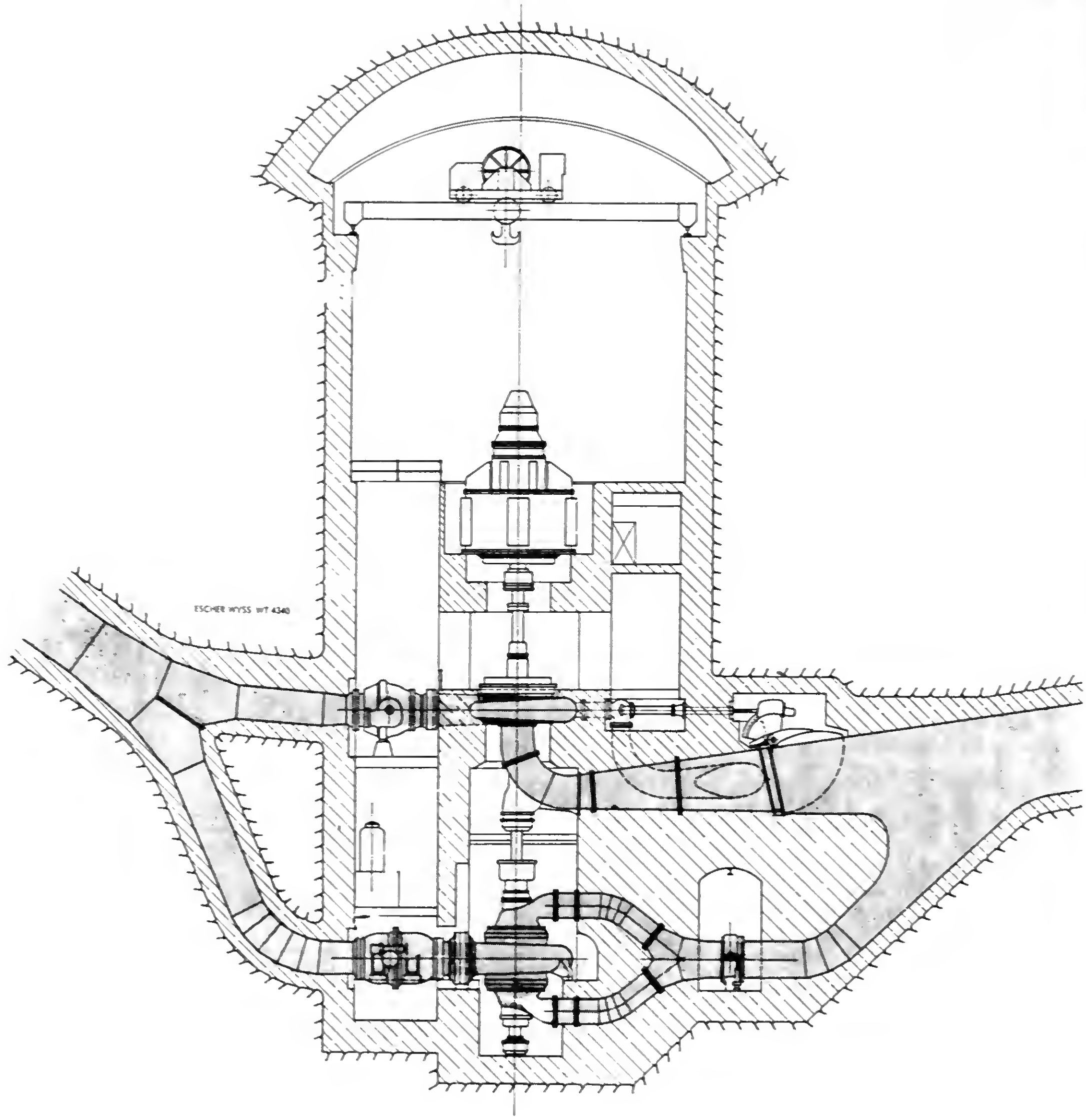



Fig. 21.5 - Cross Section of Station

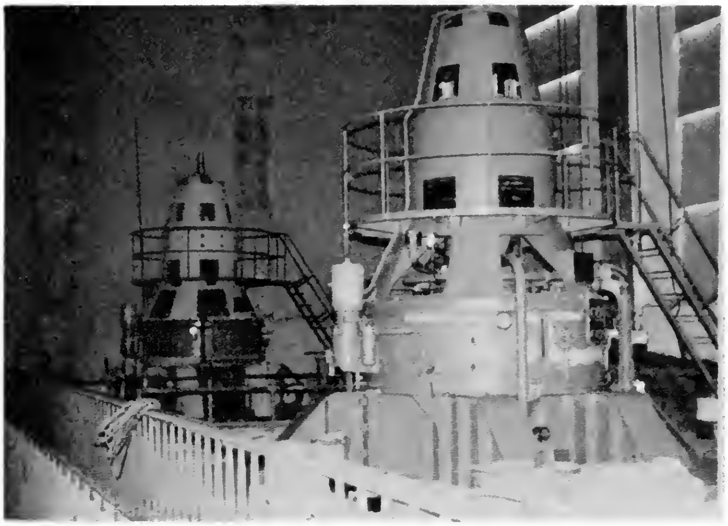


Fig. 21.6 - View of Generator Floor

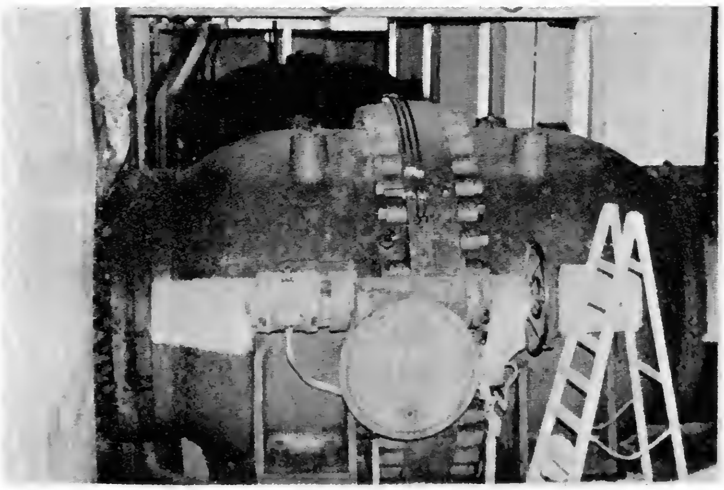


Fig. 21.7 - Needle Type Discharge Valve

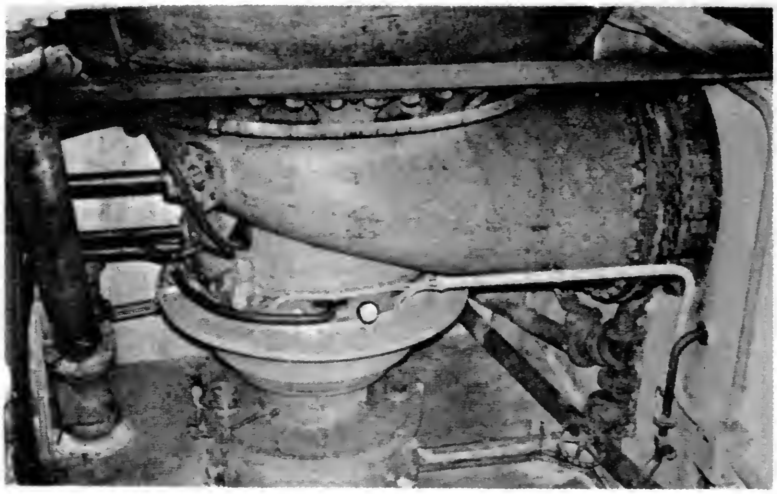


Fig. 21.8 - Pump showing Lower Inlet Fitting and Thrust Bearing

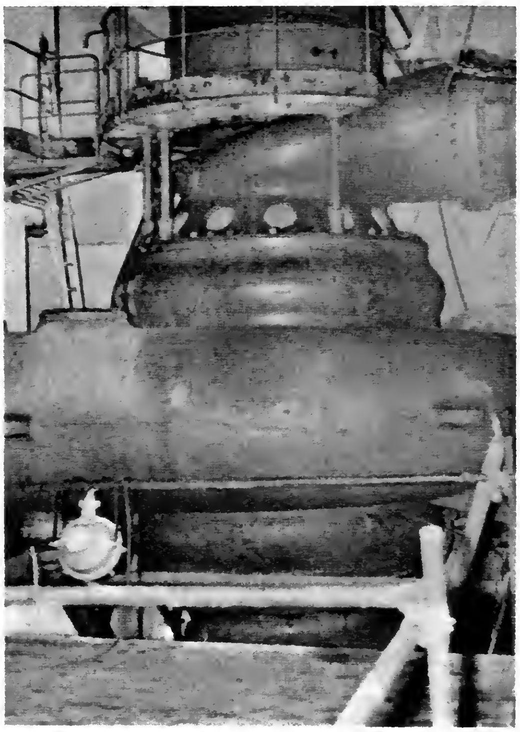


Fig. 21.9 - Pump showing Upper Inlet Elbow

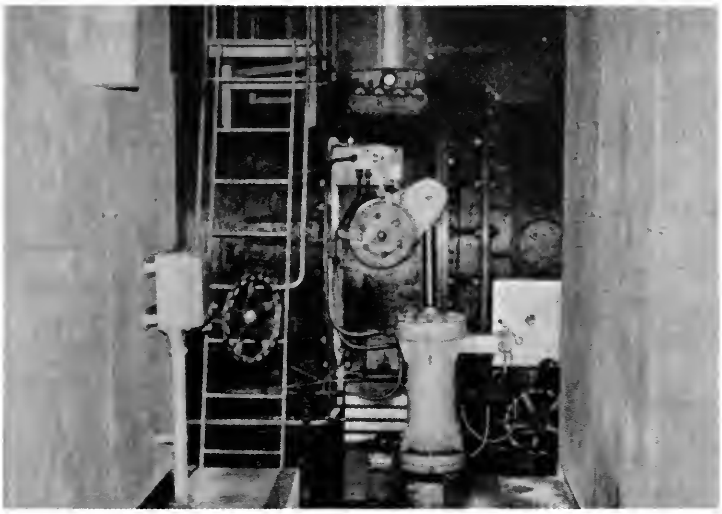


Fig. 21.10 (G6-26) Intake Butterfly Valve

Fig. 21.11 (G6-18) Impeller

<u>Vibration Records</u>

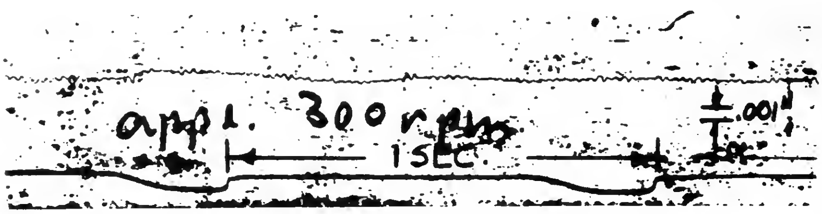
Ente Nazionale per l'Energia Elettrica (ENEL) Firenze, Italy

<u>Plant</u> : Villa Gargnano (underground power house)

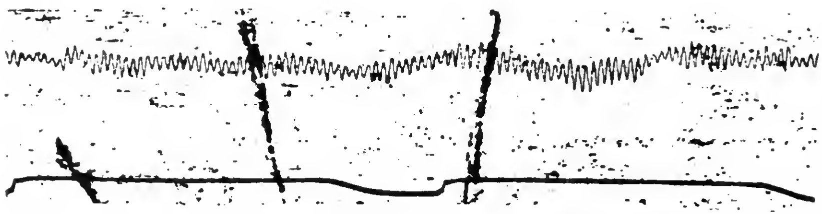
<u>Units</u> : two, 2-stage, double flow, vertical pumps; 85,000 HP, 487 cfs, 1380 ft, 600 RPM

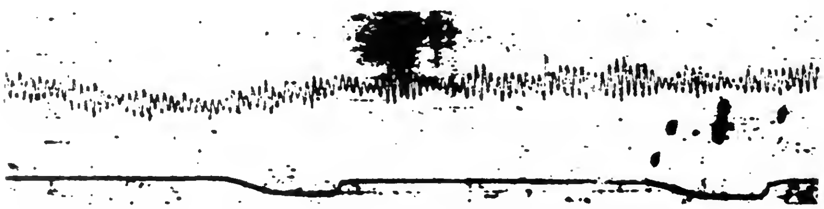
<u>Records-taken</u> : August 19, 1964

<u>Discharge Valve Closed</u>



1. Volute - speed approximately 300 rpm


2. Volute - speed approximately 500 rpm


3. Volute - speed approximately 600 rpm

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 3000 | .0004 |
| 3600 | .0015 |
| 4000 | .0015 |

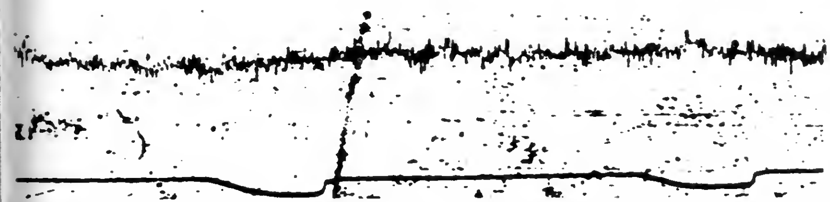
Figure 21-12

Vibration Records (cont.)

Ente Nazionale per l'Energia Elettrica (ENEL) Firenze, Italy

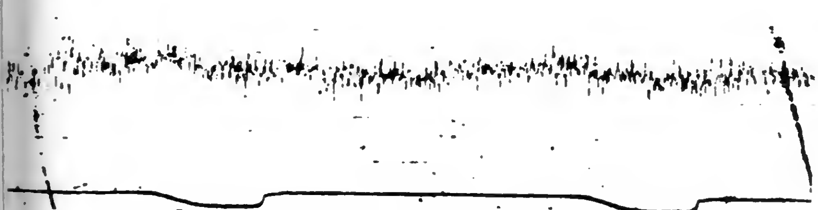
Plant : Villa Gargnano (underground power house)

Discharge Valve Closed



4. Lower suction casing - approximately 600 rpm

5. Volute - speed approximately 600 rpm



6. Volute - speed approximately 600 rpm

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 8000 | .0012 |
| 10,200 | .0031 |
| 10,200 | .0016 |

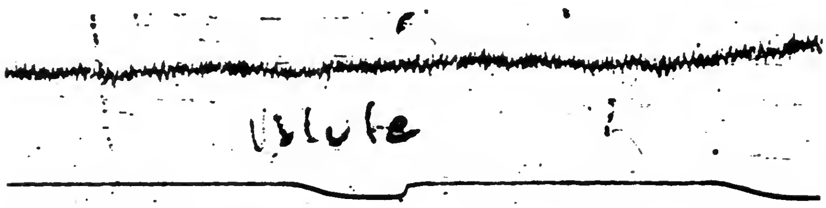
Figure 21.13

## Vibration Records (cont.)

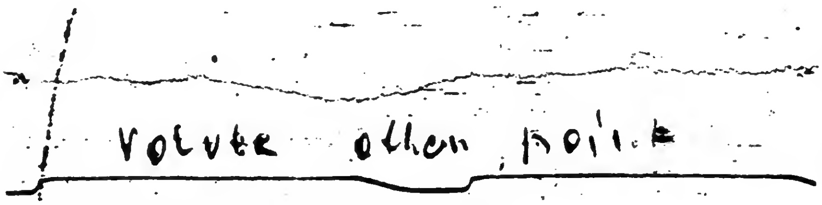
Ente Nazionale per l'Energia Elettrica (ENEL) Firenze, Italy

Plant : Villa Gargnano (underground power house)

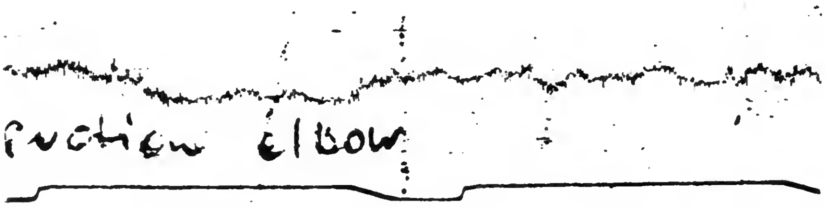
Normal Pump Operation




7. Volute casing




8. Volute casing (other point)




9. Upper suction elbow

10. Upper suction pipe

| | Frequency c.p.m. | Average Amplitude inches |
|---|---|---|
| 7. Volute casing | 16, 200 | .0008 |
| 8. Volute casing (other point) | ---- | less than .0002 |
| 9. Upper suction elbow | 10, 800 | .0006 |
| 10. Upper suction pipe | 15, 000 | .0010 |

Figure 21-14

PLANT NAME: PONALE

REPORT NO.: 22

| | |
|---|---|
| LOCATION-ALTITUDE: | North end Lake Garda, Northern Italy - 2301' |
| OWNER: | Enel (Ente Nazionale per l'Energia Elettrica S. P.A. Formerly - Società di Elettricità Ponale |
| TYPE OF PLANT: | Surface - Pump Turbine |
| SERVICE | Power to Italian Network |
| TYPE OF WATER: | Pure Lake water |
| UNITS INSTALLED: | One 4-stage single suction, horizontal turbine, pump and motor. (Was 5-stage before frequency change) |
| HORSEPOWER: | 40,000 (500 RPM) |
| CFS: | 130 |
| STATIC HEAD: | 1900' |
| PLANT STARTED: | 1) Turbine 1932 - Pump 1940 |
| VISITED BY: | Gartmann - Hartmann |
| DATE: | August 19, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Franco Vanipini, Plant Superintendent |

REMARKS:

Changed from 42 cycles (420 RPM) to 50 cycles (500 RPM) in 1964.

Has single stage, deep well booster.

1) Another small Riva Pump installed in 1954.

PUMPS:

| | |
|---|---|
| TYPE: | Horizontal - 4-stage - single suction |
| MANUFACTURER: | Riva |
| SIZE DISCHARGE: | Bottom Discharge |
| SIZE SUCTION: | Bottom Suction |
| RPM: | 500 |
| CFS: | 130 |
| HEAD: | 1900' |
| H.P. REQUIRED: | 31,500 |
| N s.: | 1180 |
| INSTALLED: | Turbine 1932; Pump 1940 |
| HRS. OF OPERATION | 38,476 |
| MIN. SUBMERGENCE: | - |
| NORMAL SUBMERGENCE: | - |
| MAX. SUBMERGENCE: | - |
| REMARKS: | - |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | - |
| PROTOTYPE-GUARANTEED: | - |
| PROTOTYPE-ACTUAL: | - |
| METHOD OF TEST: | - |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | - |
| DIAMETER IMPELLER: | 73" (1850 mm) |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 17.7" (450 mm) |
| MATERIAL CASING: | - |
| MATERIAL IMPELLER· | Stainless Steel |
| MATERIAL IMPELLER RINGS: | Bronze |
| MATERIAL-CASING RINGS: | Bronze |
| RADIAL CLEARANCE: | - |
| MATERIAL BALANCING RINGS: | (Labyrinth - Smooth) |
| MATERIAL INTERSTAGE SEAL: | Babbitt Seals |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | Cast Steel |
| BEARING: | 17" diameter |
| THRUST BEARING: | - |

| | |
|---|---|
| TYPE OF PACKING: | - |
| MATERIAL OF PACKING: | - |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | Center piece split-ends solid. No volute at inlet. |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Horizontal - Induction |
| MANUFACTURER: | CGE (General Electric Co. of Italy) |
| H. P. | 40,000 ± |
| RPM: | 470 |
| VOLTAGE: | - |
| STARTING: | - |
| REMARKS: | Pump started with main turbine |

TURBINE:

| | |
|---|---|
| TYPE: | Pelton |
| MFG: | Riva |
| HEAD: | 1900' |
| RPM: | 500 |
| H. P.: | - |
| REMARKS: | Two other Escher-Wyss Pelton Turbines in station. |

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | - |
| MANUFACTURER: | - |
| SIZE: | 39.4" (1000 mm) |
| OPERATION: | - |

DISCHARGE:

| | |
|---|---|
| TYPE: | Needle |
| MANUFACTURER: | Riva |
| SIZE: | 33.4" (850 mm) |
| OPERATION: | |
| OPENING: | - |
| CLOSING: | - |
| TIME OF CLOSING: | - |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | - |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | - |
| NO. & SIZE: | - |
| LENGTH: | - |

| | |
|---|---|
| MATERIAL: | - |
| TYPE OF UPPER GATE: | - |
| SURGE TANK: | - |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Perfectly clear water from Lake Garda. |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | Can see bottom of Lake from the shore. |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | April to July: |
| STARTS/DAY: | One per day (average) |
| HOURS OF OPERATION: | 19, 511 until 1960<br>18, 965 since 1960 |
| UNPLANNED OUTAGES: | None |
| CAUSE: | - |
| INSPECTION SCHEDULE: | Rare |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | About every 10 years |
| TIME REQUIRED: | 8 - 10 days to disassemble - 10 days to assemble. |
| IMPELLER CAVITATION: | - |

| | |
|---|---|
| SEAL RING WEAR: | - |
| NOISE LEVEL-START: | - |
| NOISE LEVEL-RUN: | - |
| VIBRATION: | - |
| REMARKS: | Pump has operated 24 years, Turbine 32 years.<br>Impeller removed in 1954 - good condition.<br>Pump inspected in 1955 - no parts replaced.<br>Babbitt seal packing replaced in 5th interstage seal in 1957-58.<br>Some wearing rings replaced. |

## GENERAL REMARKS

Ponale is a pump-turbine plant of the surface type, located in the town of Riva on Lake Garda, Northern Italy.

There is only one large pump installed in this plant which was started up in 1940. The pump is a four-stage unit with a rating of 40,000 H.P., and operates against a lead of 1903 ft., which is very close to the total lead of the Tehachapi project. The center line of the pump is at an elevation of 13' to 20' above the maximum and minimum lake level, and a vertical single-stage, Pelton turbine-driven booster pump supplies adequate suction pressure to the main pump. The pump is operated from April to August during off-peak hours.

Except for some trouble with the booster pump in the beginning, which was corrected by changing the intake piping arrangement, the unit has operated trouble-free, since its installation in 1940. The only parts that have been replaced once are the inter-stage bushings, the packing bushings (1957), and some of the wearing rings. The first-stage impeller and diffusor was changed from Cast Steel to 12% Chrome in 1948, although the reason for this change is not clear as an inspection in 1945 showed all parts to be in good condition.

The pump is started full of water against closed shut-off, by means of the Pelton type turbine installed between the Motor-Generator and the pump.


Fig. 22-1 - Large Riva Pump

Fig. 22.2 - Small Riva Pump

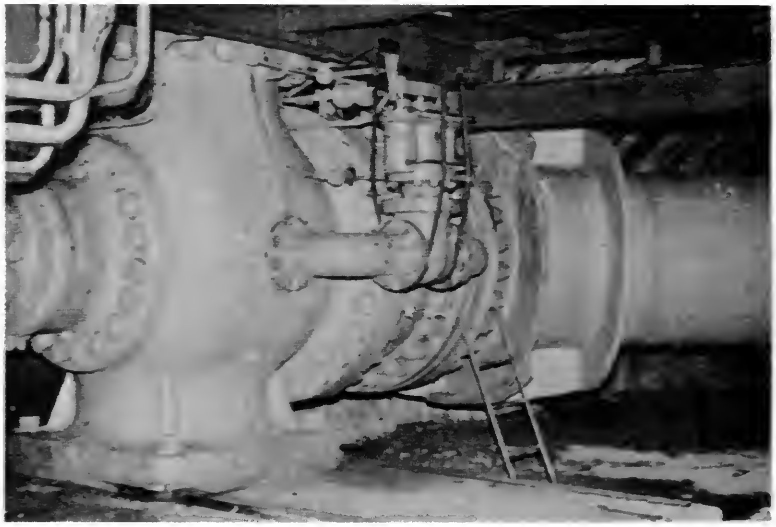


Fig. 22.3 - Discharge Valve

Fig. 22.4 - Plant Interior

PLANT NAME: FFESTINIOG

REPORT NO.: 23

| | |
|---|---|
| LOCATION-ALTITUDE: | Western Wales - 548' |
| OWNER: | Central Elec. Generating Board of England |
| ADDRESS: | London |
| TYPE OF PLANT: | Surface - Generating and Pumped storage |
| SERVICE | - |
| TYPE OF WATER: | Clean - Reused over and over |
| UNITS INSTALLED. | Four 2-stage, double suction vertical pumps with Francis turbines and generators. |
| HORSEPOWER: | 4 x 93,600 - 428 RPM |
| CFS: | 745 |
| STATIC HEAD: | 1000 |
| PLANT STARTED: | I- 12/61; II- 2/62; III- 3/63; IV- 10/63 |
| VISITED BY: | Hartmann - Cole - Westman |
| DATE: | Aug. 25, 1964 - London<br>Aug. 26, 1964 - Ffestioniog |
| PERSON(S) INTERVIEWED & TITLE(S): | Mr. Douglass, Resident Engineer in London<br>Mr. H. Headland (Kennedy & Donkin)<br>Mr. Golding, Plant Superintendent<br>Mr. Marston, Maintenance Foreman<br>Mr. R. Cole, Elec. Eng. (with K & D)<br>Mr. A. D. Longman, Resident Eng. (with K & D) |
| REMARKS: | Four units on two transformers |

PUMPS:

| | |
|---|---|
| TYPE: | Verticle - two-stage, double suction |
| MANUFACTURER: | Sulzer Bros. - Winterthur<br>English Electric |
| SIZE DISCHARGE: | 5'6" |
| SIZE SUCTION: | 2 x 5'8" |
| RPM: | 428 |
| CFS: | 745 |
| HEAD: | 1000 |
| H.P. REQUIRED: | 94,000 |
| N s.: | 1650 |
| INSTALLED: | Dec. 1961' Feb. 1962; Oct. 1962; Mar. 196 |

HRS. OF OPERATION

| | I | II | III | IV |
|---|---|---|---|---|
| Generating & Spinning | 5775 | 5333 | 3210 | 3630 |
| Pumping | 4427 | 3880 | 2342 | 2784 |

| | |
|---|---|
| MIN. SUBMERGENCE: | 43' (Upper impeller) |
| NORMAL SUBMERGENCE: | - |
| MAX. SUBMERGENCE: | 75' (Lower impeller) |
| REMARKS: | Pumps encased in concrete with 3/8" thickness of sheet rubber between casing and concrete. Suction elbows and volute casing made by English Electric. Impeller, diffuser, returns and seals made by Sulzer. |

## EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | - |
| PROTOTYPE-GUARANTEED: | 90% - 1062'; 90.6 - 1000'; 90.3 - 973' |
| PROTOTYPE-ACTUAL: | No test |
| METHOD OF TEST: | - |

## CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 5.5' |
| DIAMETER IMPELLER: | 1st stage - 96" - 2nd Stage - 101" |
| DIAMETER EYE: | 6.25' |
| DIAMETER SHAFT: | 27" Impeller shrunk-on (SKF method) |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | 13% Chrome stainless |
| MATERIAL IMPELLER RINGS· | 13% Chrome stainless |
| MATERIAL-CASING RINGS: | Aluminum Bronze |
| RADIAL CLEARANCE: | 1.5 mm to 1.78 mm |
| MATERIAL BALANCING RINGS: | None |
| MATERIAL INTERSTAGE SEAL: | Babbitt bushings |
| RADIAL CLEARANCE: | 0.8 mm to 0.10 mm |
| MATERIAL DIFFUSER: | Stainless Steel - 13% Cr. |
| BEARING: | 27" x 21" |
| THRUST BEARING: | Mitchell type at bottom - 145 ton |

| | |
|---|---|
| TYPE OF PACKING: | Labyrinth |
| MATERIAL OF PACKING: | - |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical Synchronous |
| MANUFACTURER: | Associated Electric Industries, Ltd. (AEI) |
| H. P.: | 90 MW as generator is at 95 PF (originally 75 MW) 104,000 as motor at unity PF. |
| R. P. M.: | 428 |
| VOLTAGE: | 16 kV |
| STARTING: | by Turbine |
| REMARKS: | Efficiency generating - 98.28%<br>Motoring - 98.37%<br>Runaway speed -750 RPM (175%)<br>Two motors per transformer. Generator capacity increased to meet turbine capacity by increased cooling. |

TURBINE:

| | |
|---|---|
| TYPE: | Francis - Vertical |
| MFG.: | English Electric- Sulzer |
| HEAD: | 970' (925' to 1020') |
| R. P. M.: | 428 |
| H. P.: | 105,000 |
| REMARKS: | Maximum efficiency - 93% (expected). With the four turbines filled with low pressure water, they can pick up 320 MW from spinning reserve in 55 seconds. |

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | Sliding Gates |
| MANUFACTURER: | Ransomes & Rapier, Ltd. |
| SIZE: | 14'-8" x 12'-2" |
| OPERATION: | Gantry Crane (15 ton) |

DISCHARGE:

| | |
|---|---|
| TYPE: | Spherical |
| MANUFACTURER: | English Electric Co., Ltd. |
| SIZE: | 5.5" |
| OPERATION: | - |
| OPENING: | Hydraulically from filtered Penstock pressure. Solenoid controlled. |
| CLOSING: | Same - rubber seal |
| TIME OF CLOSING: | |
| NORMAL: | 60 sec. |
| EMERGENCY: | 25 sec. |
| REMARKS: | Requires 7% minutes to start and fully load the pump. Seal ruptured on two occasions on account of mal-functioning of relays. |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | 4 x 7.5' steel - 4 x 9.4' steel lined concrete. 4 x 10.7' concrete into two 14.5' vertical pumps. |
| LENGTH: | 725' sloped + 3725' hor zontal then vertically 650' hrough two concre e lin d 14 5' shafts |

| | |
|---|---|
| MATERIAL: | Steel lined for 2700', then concrete |
| TYPE OF UPPER GATE: | Sliding gates |
| SURGE TANK: | Intake Structure |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Clean |
| Ph: | 8.32 Solids: 21.0 to 26.0 RPM (some fibrous peat growths) |
| HARDNESS: | Soft |
| REMARKS: | Alkalinity as $CaCO_3$ - 6.25 - 3.75; $O_2$ consumed at $27^oC$ 0.2 - 0.6; Lead as Pb 0.1 - 0.18; 2w 0.15; Cn 0 to .03 - Fe 0 - 0.03; Mn 0.02 to 0.06 - temp. $33^oF$ to $60^oF$. |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | Two generating and two pumping periods daily. |
| STARTS/DAY: | 3 to 8 |

HOURS OF OPERATION:

| | I | II | III | IV |
|---|---|---|---|---|
| Generating | 5775 | 5333 | 3210 | 3630 |
| Pumping | 4427 | 3880 | 2342 | 2784 |

| | |
|---|---|
| UNPLANNED OUTAGES: | None on account of Pump |
| CAUSE: | Usually mal-functioning of relays. |
| INSPECTION SCHEDULE: | None established. |
| TIME REQUIRED: | - - |
| OVERHAUL SCHEDULE: | None established. |
| TIME REQUIRED: | Expect about 9 days. |
| IMPELLER CAVITATION: | Apparently, some cavitation on top impeller of unit No. 1. Expect to remedy cavitation damage every 3-5 years (15,000 hrs.). Distinct cavitation noise in upper suction elbow. |

| | |
|---|---|
| SEAL RING WEAR: | None |
| NOISE LEVEL-START: | Noisy - 110 DB |
| NOISE LEVEL-RUN: | Noisy - 105 DB |
| VIBRATION: | Some - especially in piping. |
| REMARKS: | Thrust bearing galled once, due to dirt or air in stand-by oil pump. Quite a bit of trouble with pressure stats and limit switches, due to moisture and dust.<br><br>Stator winding bars in generator loosened due to frequent temperature changes. Corrected by installing thermostatic control of cooling water.<br><br>Although not necessary at that time, impellers of Units I and II were welded in October 1963. Three types of electrods were used; 25/10., 18/8, and 17/4 Cr. /ni Steel. |

## GENERAL REMARKS

The Ffestiniog pumped storage hydropower plant officially commissioned on 10th August 1963 by Her Majesty Queen Elizabeth in the presence of Sir Christopher Hinton, President of the Central Electricity Generating Board, is used as an example to illustrate how a large pumped storage hydropower plant operates in conjunction with thermal power stations and will subsequently be run in conjunction with a nuclear power plant.

This pumped storage hydropower plant, the first large installation of its type, was built by the Central Electricity Generating Board at a cost of 13. 5 million and is mainly employed for storing surplus energy generated in thermal power stations during the night. On completion of the Trawsfynydd nuclear power station (500 MW) at present being constructed, the Ffestiniog hydraulic pumped storage plant will also be used for regulating its frequency and output; indeed the Ffestiniog plant will be remote-controlled from the nuclear power station. Designed to generate power during the day, the plant pumps water into an elevated reservoir about 1000 ft. above the plant. This takes place over a period of 6-1/2 hours when the load on generating plant is low. The energy thus stored is then made available again during peak loads, sufficient hydraulic energy being stored to run the turbines for about 4-1/2 hours. Plant output is fed into the 275 kV grid (later to be 400 kV of the Central Electricity Authority via an open-air transformer and switchgear installation at the rear of the plant.

The Ffestiniog project commenced in April 1957, and chiefly consists of the upper reservoir, the power station building next to the lower reservoir, and the connecting penstock shafts, pressure tunnels, power penstocks and distribution penstocks. The upper reservoir was created by a concrete buttress dam about 1000 ft. long and 100 ft. high across the outlet of the Llyn Stwlan. The volume of water represented by a difference between "full" and "empty" water levels of about 68 ft. is sufficient to drive all four turbines at full load for four to five hours. The lower reservoir formed by the natural basin of the Afon Ystradau and the Tan-y-Grisiau concrete gravity dam about 1800 ft. long and 40 ft. high collects the water from the turbines and various small streams and feeds it to the pumps.

Through the intakes equipped with roller gates, water flows from the upper reservoir through two concrete-lined, vertical penstock shafts extending 640 ft. vertically below the base of the intakes. Each vertical penstock shaft then bifurcates into two pressure tunnels. The four tunnels are concrete lined for a distance of about 1650 ft. from the shaft (there is a substantial thickness of rock above them), but they are lined with steel pipe for the remaining 2100 ft. to the tunnel portals. The four steel penstocks connecting the tunnels to the station are encased in pre-stressed concrete and covered with soil. Each penstock bifurcates through a 30-ton breeches piece with a reinforcing collar, Sulzer System, the upper branch leading to the turbine inlet and the lower to the pump outlet.

Items supplied by Sulzer, i. e., steel linings for two pressure tunnels as well as all the penstocks and distribution penstocks, were manufactured from special steel of high cohesive strength. This British steel, already employed in various Sulzer penstocks on the Continent, has thus been used for the first time in a British penstock.

An excavation about 80 ft. deep was needed for the power station building on the west bank of the lower reservoir. The building above ground is of steel-framed construction. Mechanical and electrical plant consists of four vertical 80 MW units, each comprising a generator motor unit mounted on a three-part shaft about 108 ft. long, a turbine and a storage pump. During turbine operation, i. e., when power is being generated, only the Francis turbine rotates together with the rigidly coupled generator, while the gear coupling connecting the storage pump to the turbine shaft is disconnected and the storage pump stationary. When the pump is working, however, all three machines rotate, the generator acting as a motor and driving the pump and the turbine. For this mode of operation, water is discharged from the turbine casing by compressed air. When the plant is on spinning reserve the pump is disengaged and the turbine drained, while the generator runs synchronously with the mains.

The head of water available in the lower reservoir, measured to the middle of the delivery volute, varies between about 50 ft. and 68 ft. The pumps have to be able to operate at between 49 and 51 cps.

The guaranted operating data are as follows

| | | Max. Head | Design Head | Min. Head |
|---|---|---|---|---|
| Total delivery head | ft. | 1,062 | 1,000 | 973 |
| Discharge | $ft.^3$/Sec. | 664 | 745 | 773 |
| Efficiency | % | 90 | 90.6 | 90.3 |
| Speed | r.p.m. | 428 | 428 | 428 |
| Input | h.p. | 90,160 | 94,710 | 95,910 |

The type of pump selected was dictated by the mode of operation peculiar to this power station, by the topographical features of the site (head of water available in the lower reservoir) and by the location of the machinery hall. Under the prevailing conditions, double-suction, two-stage pumps running at 428 rpm proved to be the most practical proposition.

Dimensioning of the storage pumps to full scale was carried out on the basis of the investigations performed with the model and the results obtained. It was established that even if majoration were quite conservative, the efficiency of the full-size machine would exceed the guaranteed figures -- a conclusion that has been confirmed in practical operation.

The breeches piece feeds into the two pump inlets and the water is drawn from the lower storage reservoir. The water passes to the two first-stage single-entry impellers and is forced into the central double-entry second-stage impeller via the diffusors and overflow channels. The double diffusor precedes the volute casing connected to the discharge pipe., the volute casing consisting of four bolted sections seal-welded together. Heat-treated, wear-resistant 13% chrome steel was the material used for the impellers and diffusors. The casing, to which the steel-plate volute is connected, is in cast steel. Non-contact labyrinth seals reduce water leakage along the shaft.

An amply-dimensioned Michell type thrust bearing supports the weight of the runner as well as absorbing dynamic axial forces which may occur under certain circumstances and frictional forces caused by the toothed gear coupling shifting as a result of shaft expansion. The toothed gear coupling connecting with the turbine shaft is made of alloy steel (molybdenum, chromium, nickel and vanadium) and can be engaged or disengaged while the plant is stationary. It is probably the largest coupling of its type built to date. It is engaged by a hydraulic servomotor at the upper end of the pump shaft, the coupling sleeve remaining permanently engaged with the pump coupling hub. A taper lead is provided on the turbine coupling teeth to give a probability of first-time engagement of 90 to 95%. Should the teeth be directly opposed, the pump shaft automatically rotates through a distance equal to half the tooth pitch. This motion is performed by a clamping device fitted to the pump coupling hub; it exerts a pressure on the hub via a hydraulic piston and rotates the pump shaft with the aid of two servomotors.

To save wear on the running surfaces of the thrust bearing and to reduce the torque required, the rotor is lifted during engagement, clamping and barring operations. While the plant is in operation the coupling is kept engaged by hydraulic pressure and is locked mechanically to prevent disengagement while rotating. Correct location is ensured by electrical contacts.

An independent lubrication system is provided for each storage pump and consists of pumps, filter, cooler and main lube oil tank (about 1400 Imp. gal.) supplying oil under pressure to the upper and lower journal bearings, as well as to the thrust bearing. An elevated emergency oil tank having a capacity of some 380 Imp. gal. starts to fill up automatically before the storage pumps are started. It supplies lube oil in the event of oil-pump failure. Oil is cooled before being returned to the bearings. An accumulator working at 25 atm. gauge is also fed from the main oil tank and serves for controlling the toothed gear coupling and the shaft barring device. An oil pump with a working pressure of 80 atm. gauge is provided for lifting the shaft during coupling engagement.

The storage pumps can be set in operation from the control room and may also be continuously monitored from there. Before the pumps are started, the generator-motor units, turbines and pumps must be ready for starting and the upper and lower reservoir gates have to be ready for operation. Only when these conditions are fulfilled can the storage pumps be started. The various phases of the starting sequence are initiated via a drum-type controller.

Before the toothed gear coupling is engaged, the pump rotor is lifted about 5/16" and lowered again after the coupling sleeve has been engaged in the turbine coupling hub. If the coupling does not engage after about 10 seconds, i.e. if the teeth are directly opposed, the shaft barring mechanism comes into action. On completion of engagement the turbine valve can be opened to run up the turbine and automatically start the unit until the electrical machine is synchronized with the supply network. After the load has been taken over by the generator-motor unit the turbine valve is closed and the turbine dewatered by compressed air being introduced. The pump valve is then opened, permitting water to be pumped into the upper reservoir. While the unit is being run up and until the valve is opened, a protective valve is opened to prevent a rise in temperature of the water in the pump.

When the pump is being shut down, the pump valve is first closed and the protective valve opened; only then is the generator stopped. Brakes fitted to the generator-motor unit shorten the running-down time.

Prior to its being embedded in concrete and the internals being installed, the pump casing was aligned by plumb line suspended within the hollow generator-turbine shaft. A certain degree of malalignment is, however, permitted by the toothed gear coupling. Fix points in the main building are provided for checking alignment at subsequent intervals. If subsidence should occur, both the stator and rotor units complete with pump bearings can be relocated within the embedded casing.

Like the turbines and generators already in operation, the four storage pumps were commissioned on different dates. The first was commissioned on 15th December 1961, the second on 2nd February 1962, the third on 23rd November 1962 and the last one on 26th March 1963. Each storage pump was started manually with the safety systems operative. At this stage all safety devices and apparatus were checked for proper mechanical and electrical functioning.

After it had been established that the starting conditions were fulfilled, the storage pumps were driven by the turbines for a period of 15 minutes with the valves closed. Following this, they were run up again to normal running speed and all mechanical and electrical equipment checked. After this third start and completion of the run up to normal running speed the motor was synchronized, the turbine casing dewatered by blowing in compressed air and the pump valve checked for correct functioning by being actuated several times. Further starting and stopping tests were made to recheck the various safety devices and automatic systems. Subsequent continuous running for several hours furnished proof that the plant was operating properly. Much more important, however, is the fact that the two storage pumps first installed have operated without the slightest trouble during the 4000 hours they have up to now been running. The first large-scale plant of its type in Great Britain, the Ffestiniog pumped storage hydropower plant has not only given excellent service, but has demonstrated that its conception and mode of operation are thoroughly sound.

Fig. 23-1 - General View of Site

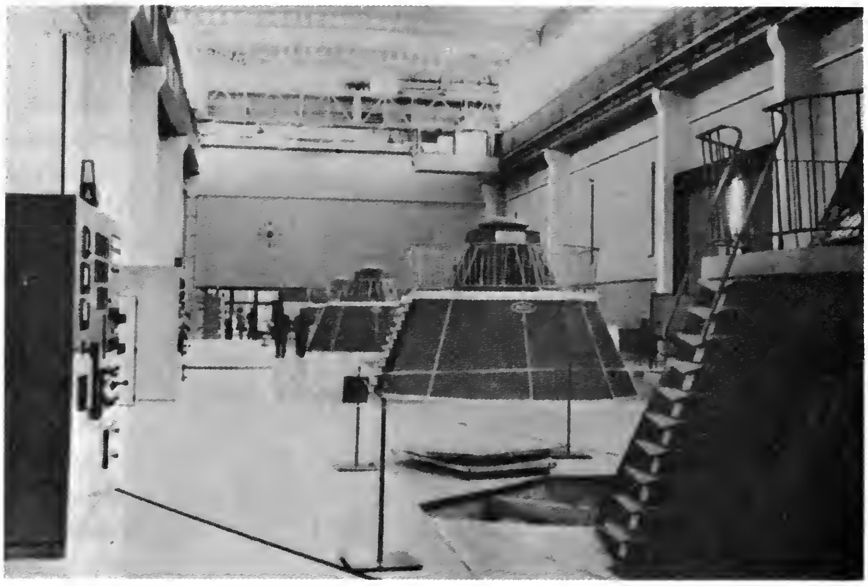
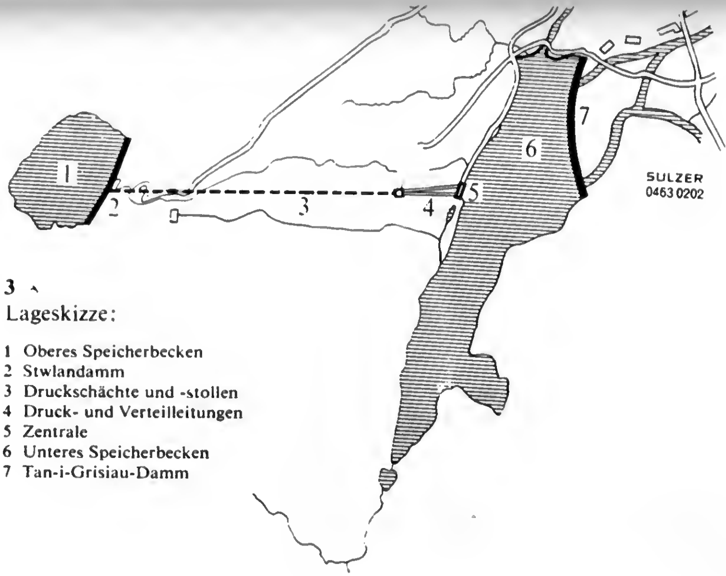


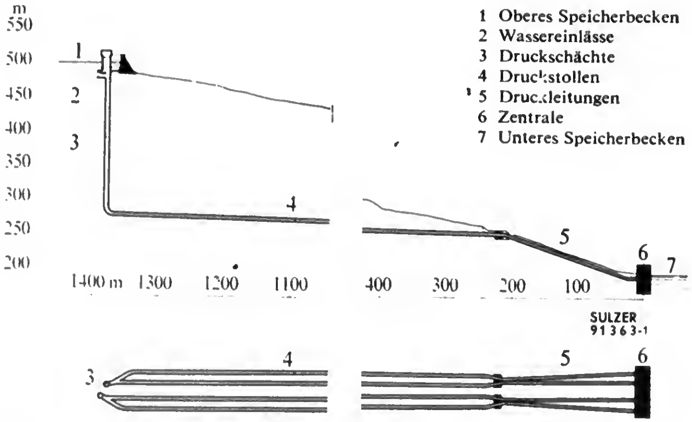
Fig. 23.2 - Motor - Generator Floor

Fig. 23.3 - View of Plant




3
Lageskizze:

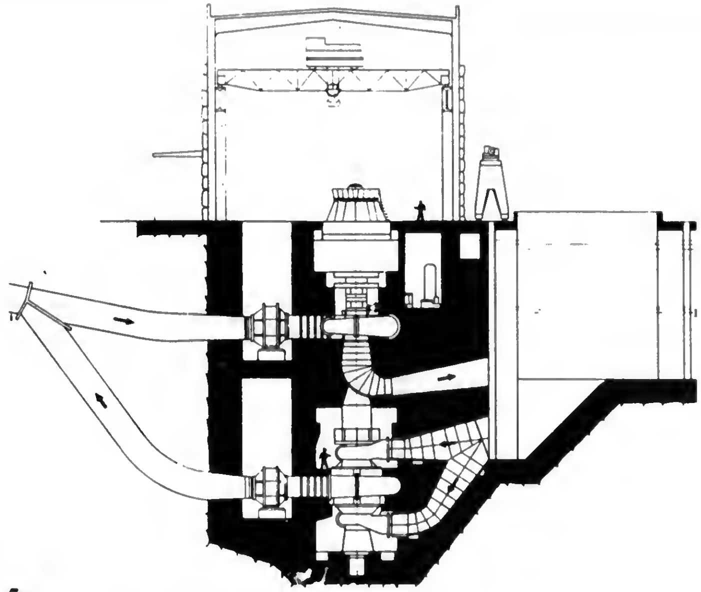
1 Oberes Speicherbecken
2 Stwlandamm
3 Druckschächte und -stollen
4 Druck- und Verteilleitungen
5 Zentrale
6 Unteres Speicherbecken
7 Tan-i-Grisiau-Damm




1 Oberes Speicherbecken
2 Wassereinlässe
3 Druckschächte
4 Druckstollen
5 Druckleitungen
6 Zentrale
7 Unteres Speicherbecken

4 A

Fig. 23-3a and Fig. 23-4a
Penstock Arrangement



5a
Querschnitt durch die Zentrale Ffestiniog.

Fig. 23-5a - Section through one unit

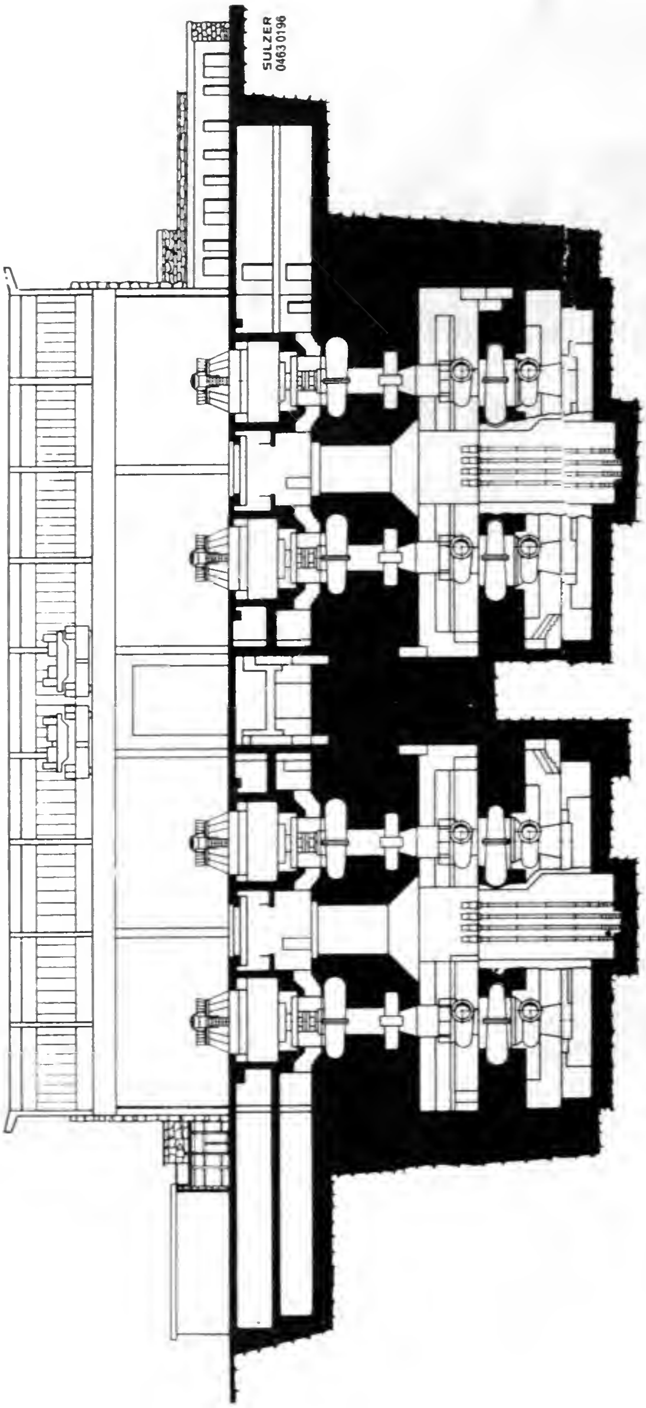



Fig. 23-5b - Longitudinal Section of Plant

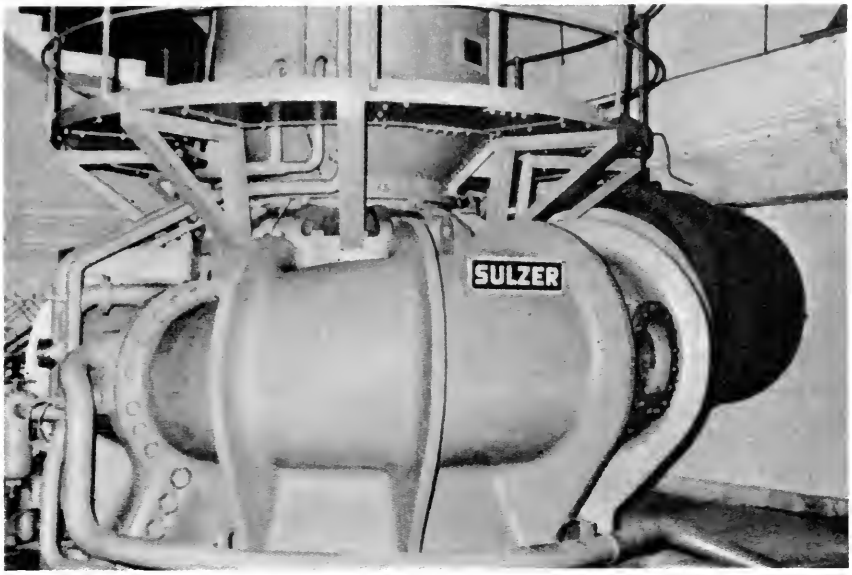



Fig. 23.4 - Pump Coupling and Top Suction Fitting


Fig. 23.5 - Pump Base and Lower Suction Fitting

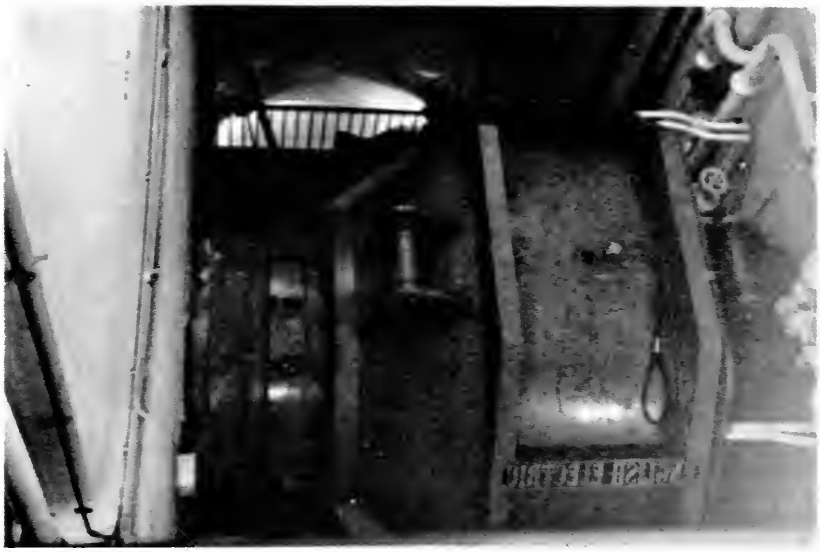


Fig. 23.6 - Turbine Inlet Spherical Valve

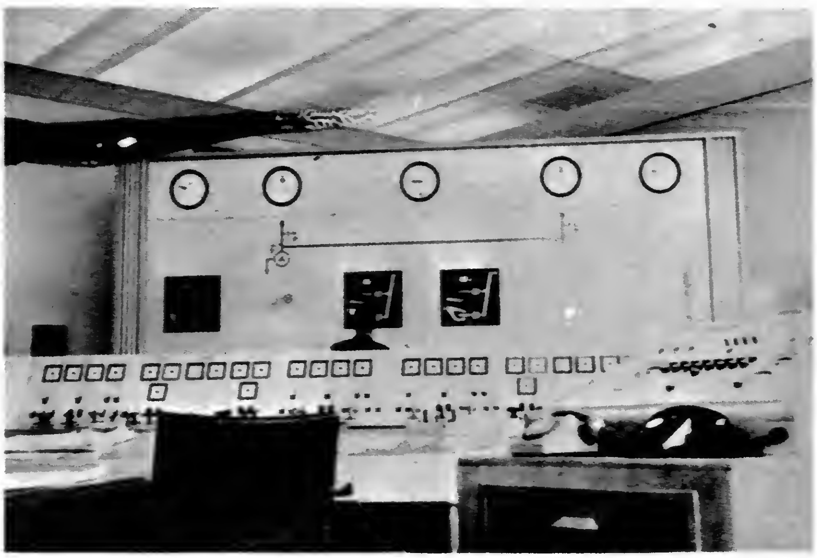


Fig. 23.7 - Control Board

## Vibration Records

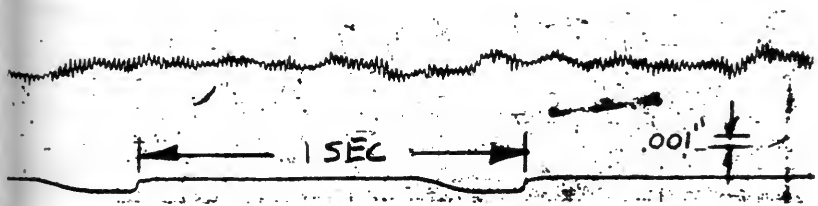
Central Electricity Generating Board, Great Britain

Plant : Ffestiniog (surface power house)

Units : four, 2-stage, double flow, vertical pumps; 93,400 HP, 745 cfs, 1000 ft, 428 RPM.

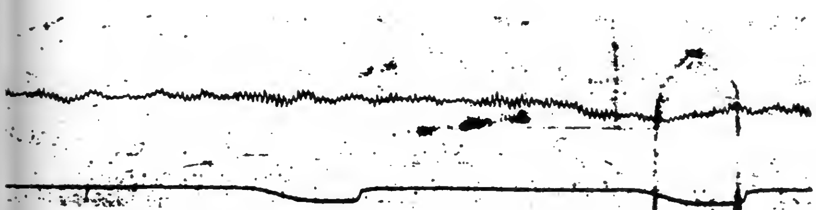
Records taken: August 25/26, 1964

Lower Suction




1. Normal Pumping, Unit #2, Point #1

2. Normal Pumping, Unit #2, Point #3



3. Normal Pumping, Unit #3, Point #1

4. Normal Pumping, Unit #3, Point #3

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 10,200 | .0015 |
| 13,200 | .0020 |
| 9600 | .0080 |
| 10,800 | .0020 |

Figure 23-8

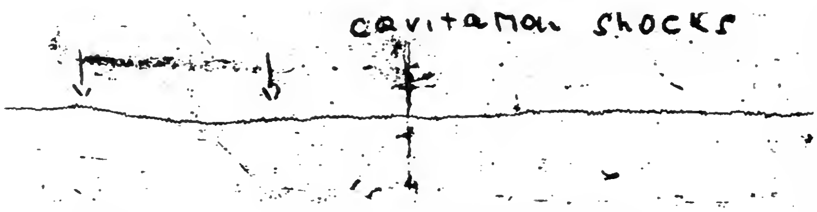
Central Electricity Generating Board, Great Britain

Plant : Ffestiniog (surface power house)

Suction Pipe

5. Normal pumping, Unit #3, Point #1

6. Normal pumping, Unit #3, Point #2, (expansion point)




7. Normal pumping, Unit #2, Point #1

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| ---- | .0002 |
| 4800 | .0015 |
| 5700 | .0004 |

Figure 23-9

## Vibration Records (cont.)

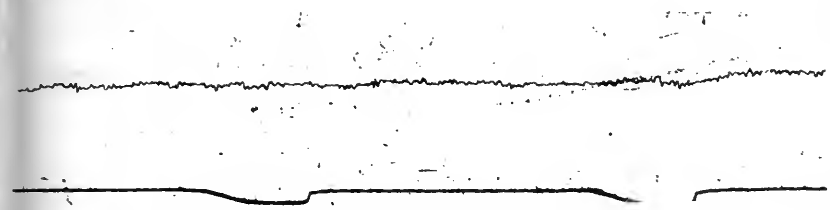
Central Electricity Generating Board, Great Britain

Plant : Ffestiniog (surface power house)

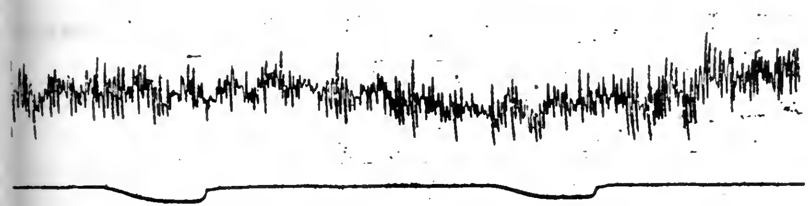
Unit #3

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 10,200<br>3600 | -----<br>.0004 |
| 7200 | .0031 |
| ---- | less than .0002 |
| 8700 | .0038 |
| 9000 | .0015 |

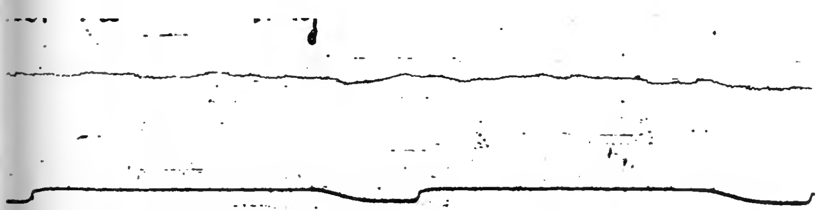
Figure 23-10



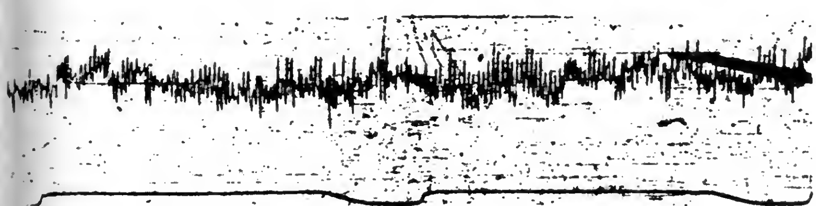
8. Upper section volute discharge valve closed



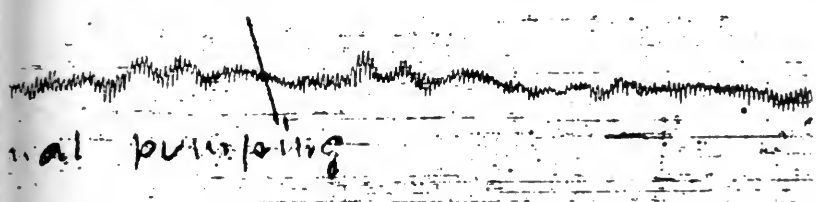
9. Suction pipe



10. Spherical valve casing



11. Suction pipe while valve is opening



12. Valve open, normal operation

PLANT NAME: ETZELWERK

REPORT NO.: 24

| | |
|---|---|
| LOCATION-ALTITUDE: | Lake Zurich - Near Altendorf, Switzerland<br>1320' |
| OWNER: | Etzelwerk A. G. (55% SBB* - 45% NOK**) |
| ADDRESS: | Zurich, Switzerland |
| TYPE OF PLANT: | Turbo-Generation - Pump Storage - Surface |
| SERVICE | Furnishing power to SBB at 16-2/3 cycles and to NOK at 50 cycles. |
| TYPE OF WATER: | Lake Water |
| UNITS INSTALLED: | (6) Pelton Turbines; Units III & IV have 5-stage, Single-Suction Pumps |
| HORSEPOWER: | Pumps - III - 20,100; IV, 25,500 500 RPM |
| CFS: | 92 113 |
| STATIC HEAD: | 1600 (Max.) |
| PLANT STARTED: | Pumps - 1947 |
| VISITED BY: | Hartmann and Cole |
| DATE: | Sept. 10, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Fritz Mächer - Plant Supt.<br>A. Meier - Shift Foreman<br>Alfred Ziegler - Director |

REMARKS: * SSB - Switzer Bundesbakn (Swiss Federal Railways)
** NOK - Nordostschweizer Krattwerke (Northeast Swiss Power Co.)

Lower basin is Lake Zurich at 1340' - Upper basin Lake Sihl at a maximum level of 2920'. Station used to keep Lake full in the Winter.

PUMPS:

| | |
|---|---|
| TYPE: | Vertical - Single-Suction - 5-stage 500 RPM |
| MANUFACTURER: | Sulzer and Escher Wyss Jointly |
| SIZE DISCHARGE: | 31.5" (800 mm) |
| SIZE SUCTION: | - |
| RPM: | 500 |
| CFS: | III - 92; IV - 113 |
| HEAD: | 1575 |
| H.P. REQUIRED: | 19,200 23,500 |
| N s.: | 1365 1510 |
| INSTALLED: | 1947 |
| HRS. OF OPERATION | III- 13,417; IV- 29,202 (end July 1964) |
| MIN. SUBMERGENCE: | 19.7' |
| NORMAL SUBMERGENCE: | 20.8 |
| MAX. SUBMERGENCE: | 20.8 |
| REMARKS: | The first pump installed exceeded expected capacity by 10%, so the second was furnished with smaller impellers. However, this pump lacked 10% of coming up to expected capacity, hence, the difference in capacity of two presumably identical pumps. |

## EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | No Model |
| MODEL ACTUAL: | " " |
| PROTOTYPE-GUARANTEED: | 85.6 to 86% |
| PROTOTYPE-ACTUAL: | III - 87 IV - 86 |
| METHOD OF TEST: | Current meters in Penstock (Tests made by Prof. Gerber in Sept. 1948) |

## CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 31.5" - (800 mm) |
| DIAMETER IMPELLER: | 64" |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 15.75" (400 mm) |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | Bronze |
| MATERIAL IMPELLER RINGS: | Bronze |
| MATERIAL-CASING RINGS: | Cast Iron |
| RADIAL CLEARANCE: | - |
| MATERIAL BALANCING RINGS: | Bronze |
| MATERIAL INTERSTAGE SEAL: | Bronze |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | Cast Iron |
| BEARING: | 12.6" Dia. |
| THRUST BEARING: | 38.5" O.D. (100,000 KG) |

| | |
|---|---|
| TYPE OF PACKING: | Labyrinth Gland |
| MATERIAL OF PACKING: | Babbitt |
| MATERIAL OF SLEEVE: | Bronze |
| CLEARANCE: | - |
| REMARKS: | Mitchel Thrust Bearing incorporated into the pump. |

MOTOR OR GENERATOR:

| | | |
|---|---|---|
| TYPE: | | Vertical - Synchronous |
| | I II III | Single-phase - 12-2/3 cycles |
| | IV V VI | Three-Phase 50 cycles |
| MANUFACTURER: | I II III - Brown Boveri; IV V VI - MFO | |
| H.P.: | III- 20,100 IV- 25,500 | |
| R.P.M.: | 500 | |
| VOLTAGE: | 10,000 | |
| STARTING: | By Turbine | |
| REMARKS: | - | |

TURBINE:

| | |
|---|---|
| TYPE: | Pelton |
| MFG.: | I, III, IV, VI - Escher Wyss<br>II, V - Bell |
| HEAD: | 1580' $\pm$ |
| R.P.M.: | 500 |
| H.P.: | 24,200 |

## VALVES:

| | |
|---|---|
| INTAKE: | - |
| TYPE: | Flapper |
| MANUFACTURER: | Escher Wyss |
| SIZE: | 43.3" x 31.5" |
| OPERATION: | Hydraulic |

## DISCHARGE:

| | |
|---|---|
| TYPE: | Spherical |
| MANUFACUTRER: | Escher Wyss |
| SIZE: | 31.5" - 25.6" - 29.5" |
| OPERATION: | |
| OPENING: | Hydraulic with water from Penstock |
| CLOSING: | " " " " " |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |

REMARKS: Discharge valve consists of 800 mm Valve combined with Venturi with 650 mm throat, and a 750 mm manually operated revision valve on downstream side. In case of power failure, turbine takes over.

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG: | Surface to Tunnel |
| NO. & SIZE: | 2 x 6.4' |
| LENGTH: | 6700 ± |

| | |
|---|---|
| MATERIAL: | Steel |
| TYPE OF UPPER GATE: | 2 - 6.9' BF at tunnel inlet<br>1 - 9.85' BF at Lake inlet |
| SURGE TANK: | At tunnel entrance |
| REMARKS: | Final tunnel - 9900' long (A pressure tunnel). |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Pure Lake water |
| Ph: | - |
| HARDNESS: | Soft |
| REMARKS: | Exceptionally good and clear water - no solids |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | Operated daily in Winter |
| STARTS/DAY: | One in operative season. |
| HOURS OF OPERATION: | III - 13,417<br>IV - 29,202 |
| UNPLANNED OUTAGES: | None |
| CAUSE: | - |
| INSPECTION SCHEDULE: | None |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | None |
| TIME REQUIRED: | - |
| IMPELLER CAVITATION: | Slight |

| | |
|---|---|
| SEAL RING WEAR: | None |
| NOISE LEVEL-START: | A: 100 - 2; B: 100 + 4 |
| NOISE LEVEL-RUN: | A: 90 + 4; B: 100 -1; C: 100 + 1 |
| VIBRATION: | Some, but not excessive. |
| REMARKS: | Pumps rather noisy -- somewhat noisier than average. |

## GENERAL REMARKS

This plant consists of six Pelton turbines driving vertical generators, two of which can be coupled to Sulzer, five-stage, single suction pumps with capacities of 2.5 m/3s (91.8 cfs) and 3.2 m/3s (113.1 cfs) respectively, at 480 meters (1540') at 500 rpm.
*)

Starting is accomplished by the Pelton turbines with water in the pumps.

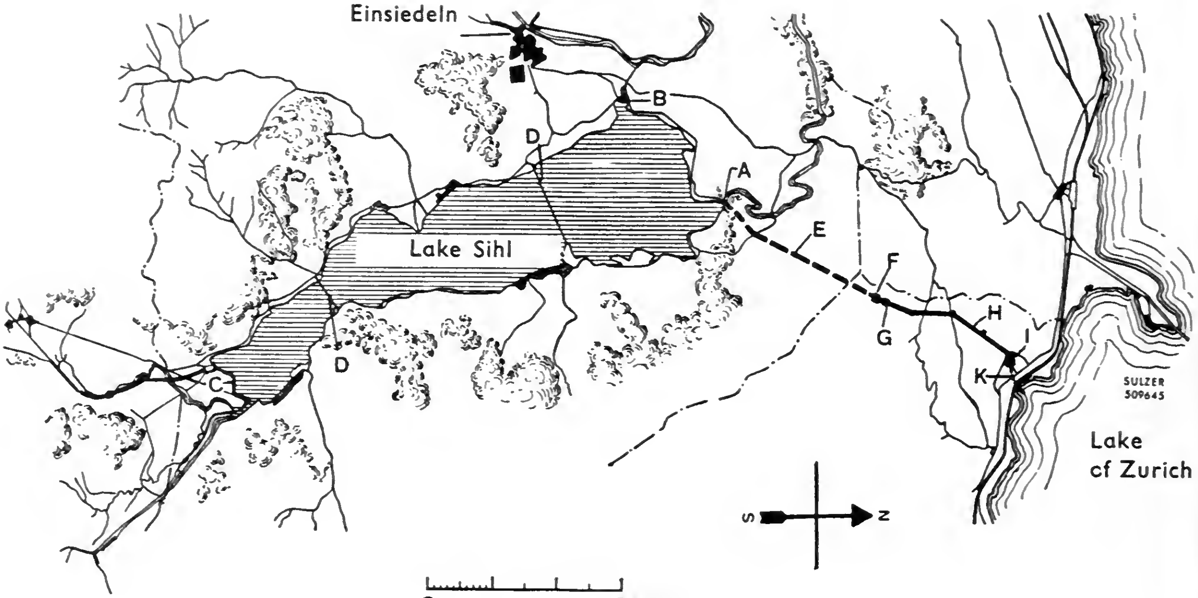
The normal submergence is 6.35 m (21'). During operation there is a slight cracking noise at the suction, possibly indicating some cavitation.

One pump was started for our observation. There was no serious vibration. The noise level was rather high in our opinion. Aside from the slight cracking sound, there was a rather loud hum similar to propeller type aeroplane warming up its motors. During the start the meter read:

| | | |
|---|---|---|
| | A : | 100 - 2 |
| | B : | 100 + 4 |
| <u>Running</u>: | A : | 90 + 4 |
| | B : | 100 - 1 |
| | C : | 100 + 1 |

The pump is hung from brackets and rolled to one side for servicing.

*) The plant is owned jointly by the Swiss National Railways and the North-East Power Co., and furnishes energy at 10 kV; three at 50 cycles and three at 16-2/3 cycles.




*A* In den Schlagen Dam
*B* Hühnermatt Dam
*C* Upper dam
*D* Road bridges
*E* Tunnel
*F* Surge tank
*G* Shut-off valve
*H* Pipe line
*I* Altendorf Power Station
*K* Tail-race tunnel

Fig. 24. 1 - Plan of Etzelwerk System

*A* Dam
*E* Tunnel
*F* Surge tank
*G* Shut-off valve
*H* Pipe line
*I* Altendorf Power Station
*K* Tail-race tunnel

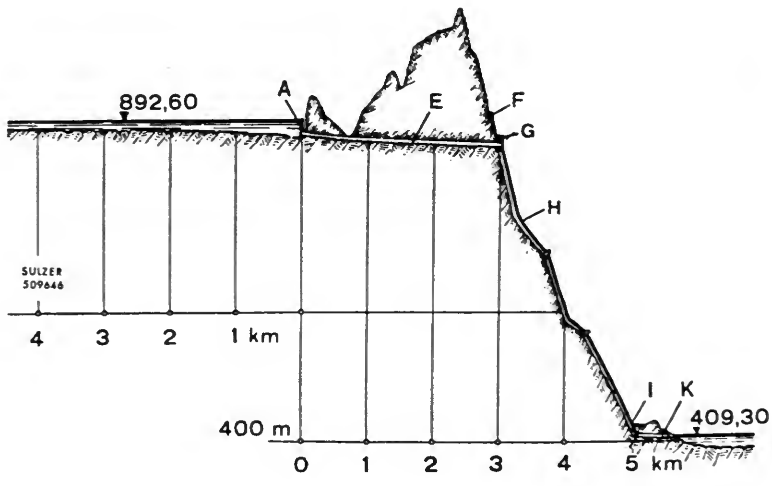



Fig. 24. 2 - Profile of Etzelwerk System

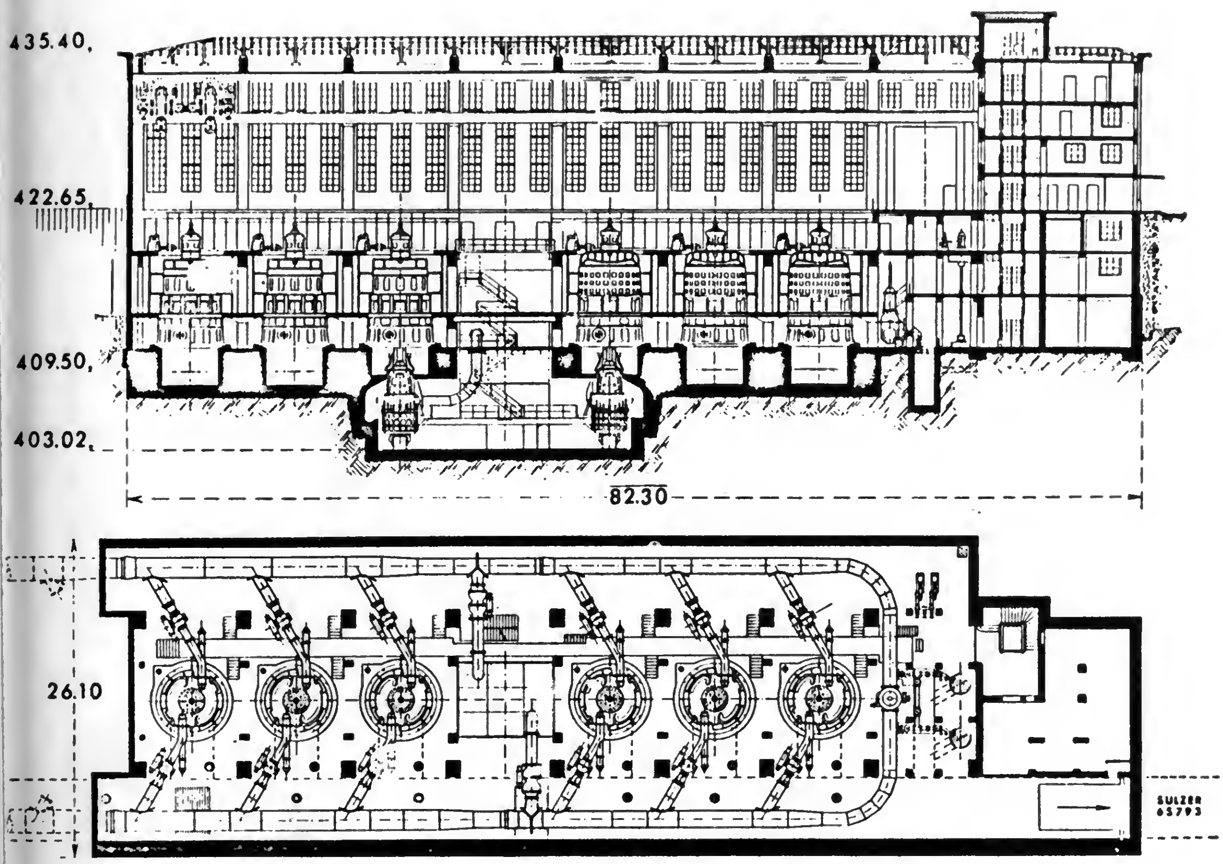



Fig. 24. 3 - Plan of Etzelwerk Station

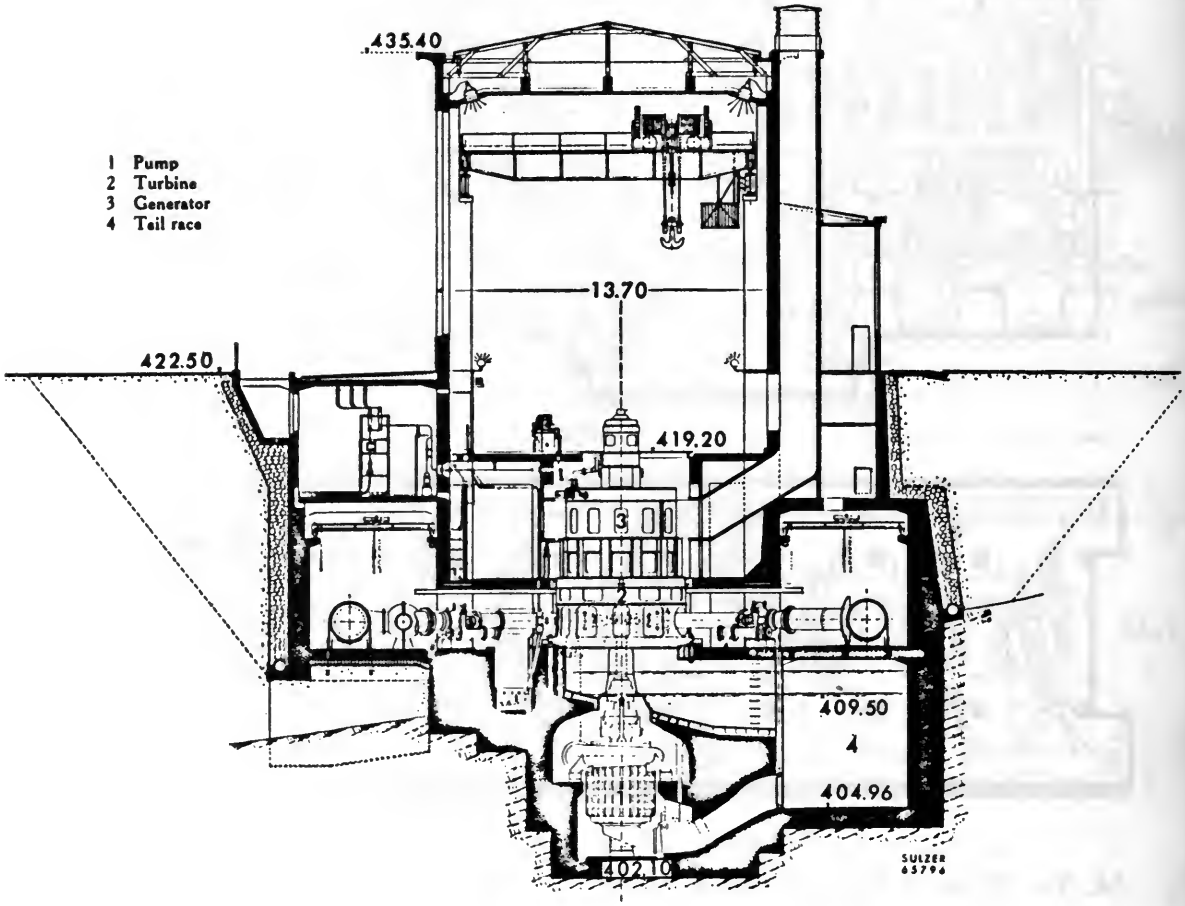



Fig. 24.4 - Section through Station

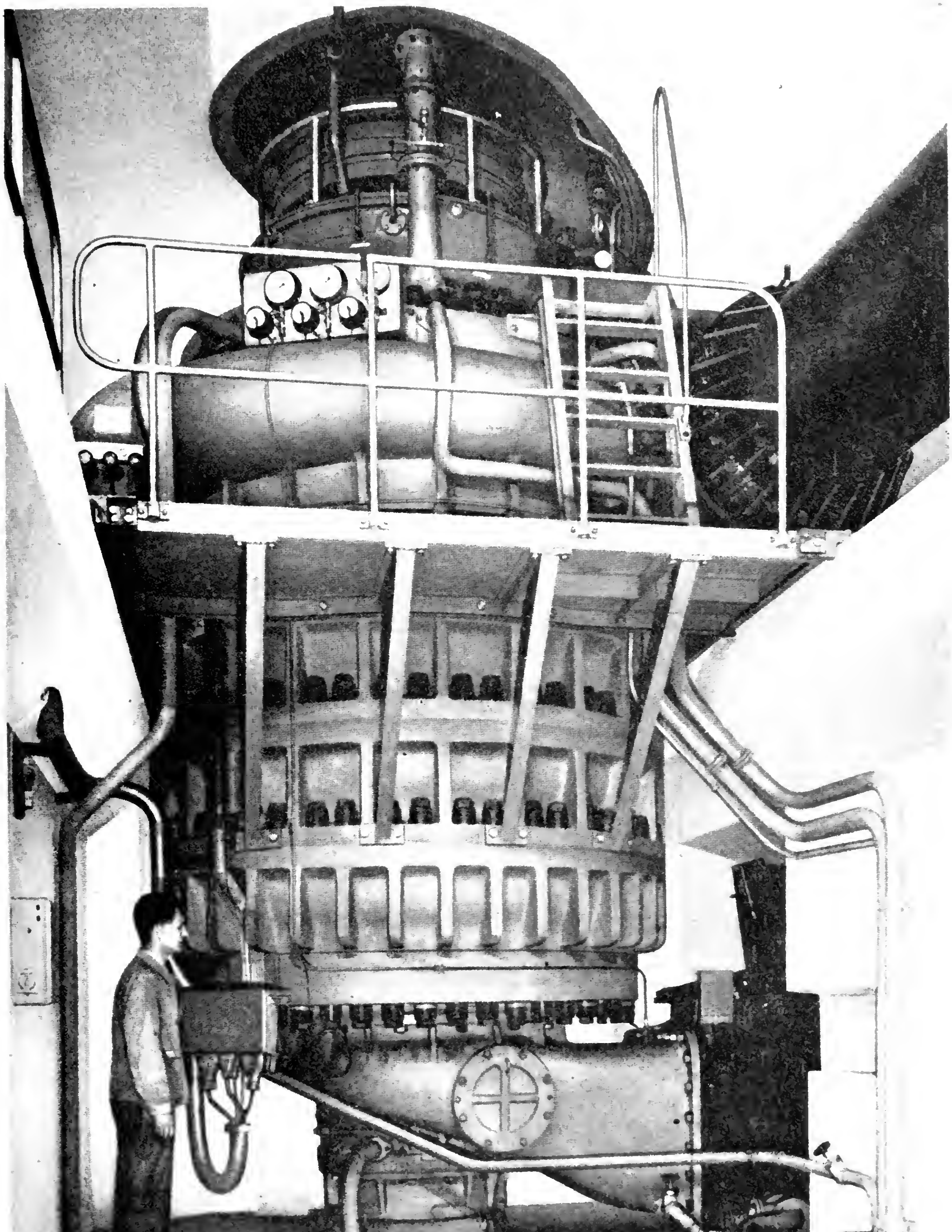


Fig. 24.5 - View of Sulzer Pump

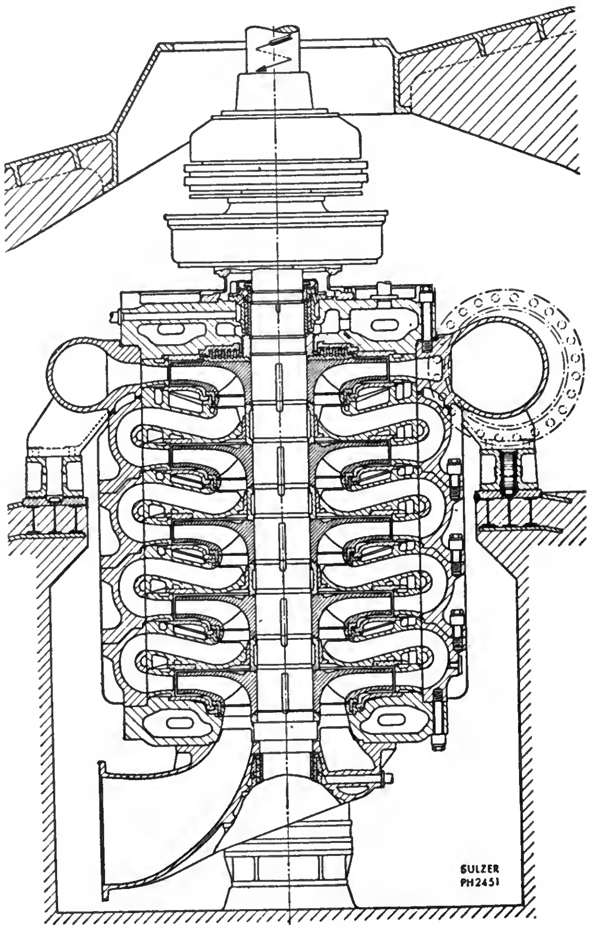



Fig. 24.6 - Longitudinal Section of Pump

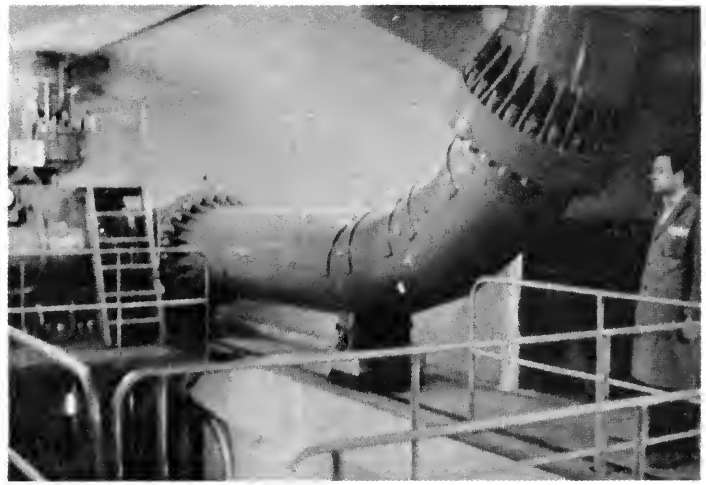


Fig. 24.7 (H 31) Discharge Pipe

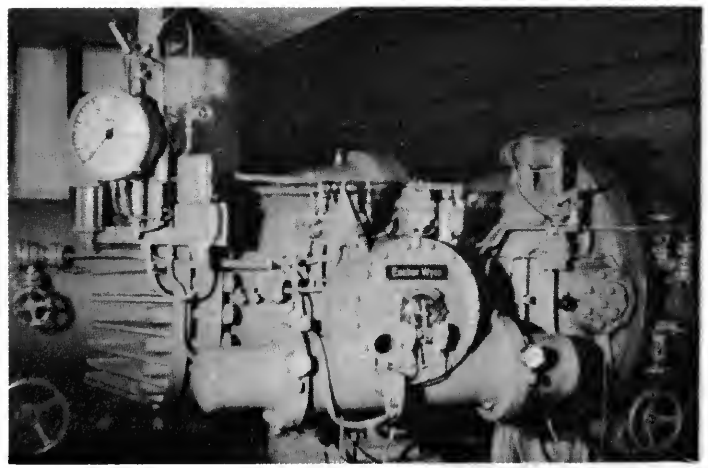


Fig. 24.8 (H 23) Discharge Valve

## Vibration Records

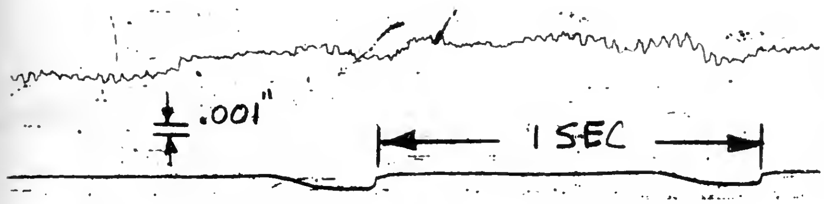
Etzelwerk A. G., Zurich, Switzerland

Plant : Etzelwerk (surface power house)

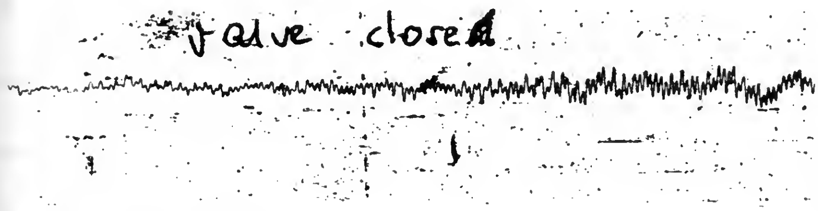
Units : one (unit #1), 5-stage, single flow, vertical pump; 19,200 HP, 92 cfs, 1575 ft, 500 RPM.
one (unit #2), 5-stage, single flow, vertical pump; 23,500 HP, 113 cfs, 1575 ft, 500 RPM.

Records taken: September 10, 1964

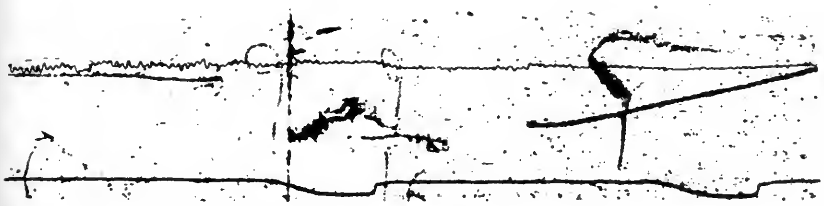
Unit #1




1. Shut down, spherical valve, valve closing frequency is irregular while maintaining the same average amplitude




2. Valve closed



3. Valve casing, valve closed, speed decreasing

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 3600 to 5100 | .0005 |
| 7500 | .0009 |
| 3600 to 1000 | .0007 to less than .0002 |

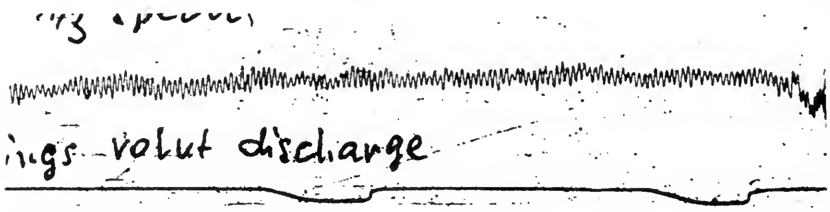
Figure 24-9

## Vibration Records (cont.)

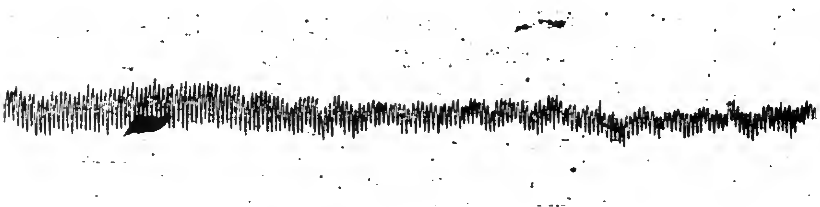
Etzelwerk A. G., Zurich, Switzerland

Plant : Etzelwerk (surface power house)

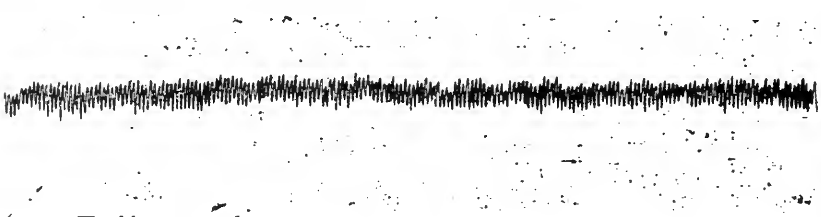
Volute Discharge




4. One-third speed



5. Nearly full speed



6. Full speed

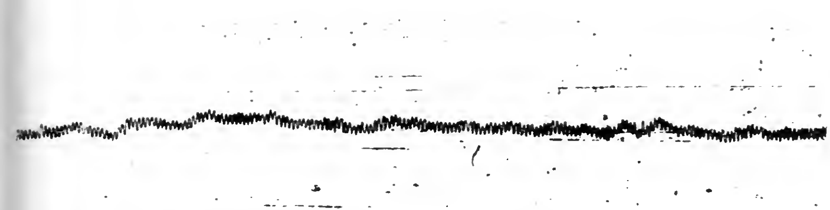
| | Frequency c.p.m. | Average Amplitude inches |
|---|---|---|
| 4. One-third speed | 3600 | .0016 |
| 5. Nearly full speed | 5400 | .0025 |
| 6. Full speed | 5700 | .0017 |

Figure 24-10

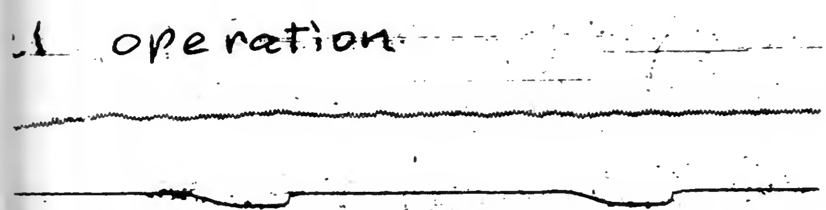
Vibration Records (cont.)

Etzelwerk A. G., Zurich, Switzerland

Plant : Etzelwerk (surface power house)



7. Valve opens




8. Normal operation

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 5700 | .0007 |
| 5800 | .0004 |

Figure 24-11

PLANT NAME: TIERFEHD

REPORT NO.: 25

| | |
|---|---|
| LOCATION-ALTITUDE: | Linthal, Switzerland - 3680' |
| OWNER: | Kraftwerke Linth Limmern A. G. (85% Northeast Swiss Power Co. 15% Canton of Glarus) |
| ADDRESS: | Linthal, Glarus, Switzerland |
| TYPE OF PLANT: | Underground - Pump Storage |
| SERVICE | Power Generation for Utility |
| TYPE OF WATER: | Rainwater, often poluted by glacial silt |
| UNITS INSTALLED: | Two - horizontal - 3-stage single-suction pumps and five horizontal Pelton Turbine generating sets. |
| HORSEPOWER: | Pumps 2 x 22,700 H. P. - 1000 R. P. M. |
| CFS: | 111 to 89.3 |
| STATIC HEAD: | 1530 to 1880 |
| PLANT STARTED: | Nov. 1963 (regular service March 1964) |
| VISITED BY: | Hartmann - Cole |
| DATE: | September 11, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Otto Bächtiger, Plant Superintendent |

REMARKS: Pumps have 1540' submergence, therefore, discharge pressure is around 3400' Main pump and turbine room 512' x 85' - horseshoe with 41' radius. Access tunnel 610' long, 18' x 18' with 9' radius roof, excavated from sandstone. Pumps deliver water to 90 million $M^3$ reservoir at 6100' elevation (maximum).

PUMPS:

| | | |
|---|---|---|
| TYPE: | Horizontal 3-stage - single suction | |
| MANUFACTURER: | Sulzer Bros. - Winterthur | |
| SIZE DISCHARGE: | 21.6" (550 mm) | |
| SIZE SUCTION: | - | |
| RPM: | 1000 | |
| CFS: | 111 to 89.3 | |
| HEAD: | 1530' to 1880' | |
| H.P. REQUIRED: | 22,700 | 21,500 |
| N s.: | 2070 | 1180 |
| INSTALLED: | November 1963 | |
| HRS. OF OPERATION | Approximately 700 each | |
| MIN. SUBMERGENCE: | 1560' | |
| NORMAL SUBMERGENCE: | - | |
| MAX. SUBMERGENCE: | 1575' | |
| REMARKS: | Excessively unusual submergence, but also unusually high discharge pressure - 3400' | |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | No Model |
| MODEL ACTUAL: | - |
| PROTOTYPE-GUARANTEED: | 1880' - 87.5%; 1770' - 88%; 1530' - 85% |
| PROTOTYPE-ACTUAL: | No test, will be made in 1965 |
| METHOD OF TEST: | - |

CONSTRUCTION DETAILS: -

| | |
|---|---|
| DIAMETER DISCHARGE: | 21.6" (550 mm) |
| DIAMETER IMPELLER: | 47.25" (1200 mm) |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 15.75" (400 mm) |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | Stainless 13% Cr. |
| MATERIAL IMPELLER RINGS: | Bronze |
| MATERIAL-CASING RINGS: | Cast Iron |
| RADIAL CLEARANCE: | - |
| MATERIAL BALANCING RINGS: | Rotating - Bronze; Sta. Cast Iron |
| MATERIAL INTERSTAGE SEAL. | Bronze - Stainless Steel |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER· | Stainless - 13% Cr. |
| BEARING: | 13.8" dia. combined with Thrust |
| THRUST BEARING: | 36" O. D. |

| | |
|---|---|
| TYPE OF PACKING: | Labyrinth Gland |
| MATERIAL OF PACKING: | None |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |

REMARKS: Pump has no handholes for inspection. To service or inspect the pump, it must be stripped from outboard bearing end.

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Horizontal - Synchronous |
| MANUFACTURER: | Brown Boveri |
| H. P.: | 22,800 |
| R. P. M.: | 1000 |
| VOLTAGE: | 9500 |
| STARTING: | Reduced voltage |

REMARKS: Motor starts with "Korndorfer-Schaltung" starts 60% voltage, then full voltage at 90% speed. Voltage drops from 9.5 to 8.0 kv on starting.

TURBINE:

| | | |
|---|---|---|
| TYPE: | Horizontal Pelton - 3 double - 2 single | |
| MFG.: | Vevey | |
| HEAD: | Dbl. 3410' | Sgl. 1580' |
| R. P. M.: | 600 | 428.6 |
| H. P.: | 116,500 | 26,800 |

REMARKS: No connection between pumps and Turbine sets.

## VALVES:

### INTAKE:

| | |
|---|---|
| TYPE: | Spher'cal |
| MANUFACTURER: | Von Roll |
| SIZE: | 23.6" (600 mm) |
| OPERATION: | Hydraulic - Penstock Water |

### DISCHARGE:

| | |
|---|---|
| TYPE: | Needle - Double Active |
| MANUFACTURER: | Von Roll |
| SIZE: | 21.6" (500 mm) |
| OPERATION: | |
| OPENING: | Hydraulic - Penstock Water |
| CLOSING: | - |
| TIME OF CLOSING: | |
| NORMAL: | 80% - 8 Sec.; 20% - 20 Sec. |
| EMERGENCY: | - |
| REMARKS: | - |

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | 1 x 5.25' |
| LENGTH: | Horizontal 466' - 75% scope 2415', then to 6.57' tunnel with 6.197% slope, approximately 7,600'. |

| | |
|---|---|
| MATERIAL: | Steel-lined (10-15 mm) |
| TYPE OF UPPER GATE: | None |
| SURGE TANK: | Underground surge reservoir at entrance to horizontal tunnel. |
| REMARKS: | - |

| | |
|---|---|
| WATER QUALITY: | Rain runoff and glacial melt. |
| GENERAL: | Contains sand and humus after rains. |
| Ph: | - |
| HARDNESS: | Soft |
| REMARKS: | Glaciel silt of limestone. Not considered very abrasive. |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | Nights during Summer. |
| STARTS/DAY: | One |
| HOURS OF OPERATION: | Now approx. 700 each. Normally about 1000 hrs. /year. |
| UNPLANNED OUTAGES: | None |
| CAUSE: | - |
| INSPECTION SCHEDULE: | Expect to inspect this winter. |
| TIME REQUIRED: | Unknown |
| OVERHAUL SCHEDULE: | None Established. |
| TIME REQUIRED: | Unknown |
| IMPELLER CAVITATION: | None |

| | |
|---|---|
| SEAL RING WEAR: | None |
| NOISE LEVEL-START: | A: 90-2; B: 90+2; 2: 90+0 |
| NOISE LEVEL-RUN: | A: 80+5; B: 90-2; C: 90-1 |
| VIBRATION: | None |
| REMARKS: | Starts and runs smoothly and quietly. |

## GENERAL REMARKS

The combined pumping and hydro-electric generating plant, owned by the Kraftwerk Linth-Limmern, consists of five horizontal Pelton turbine generating sets, two of them single turbine and three double turbine sets, and two Sulzer horozintal three-stage as pumps driven by 26, 000 HP motors at 1000 rpm. The pumps are rated at 2750 l/s (97. 1 cfs) at 542 m (1780'). They take water from Hintersand collector, 1540' above the pumps and deliver it to a reservoir 3400' above the pump. Therefore, whereas the TDH is only 1780', the discharge pressure is around 3400'. This is an underground plant, excavated from sandstone. The main pump and turbine room is 512' long by 85' wide. The section is a horse-shoe with a radius of 41'. The access tunnel is 610' long by 18' x 18' with a 9' radius roof.

The pump starts full of water, comes up to speed, and operates with a minimum of noise and vibration.

The pump has a solid case and no handholes for inspection. To service or inspect the pump, it must be stripped from the outboard bearing end.

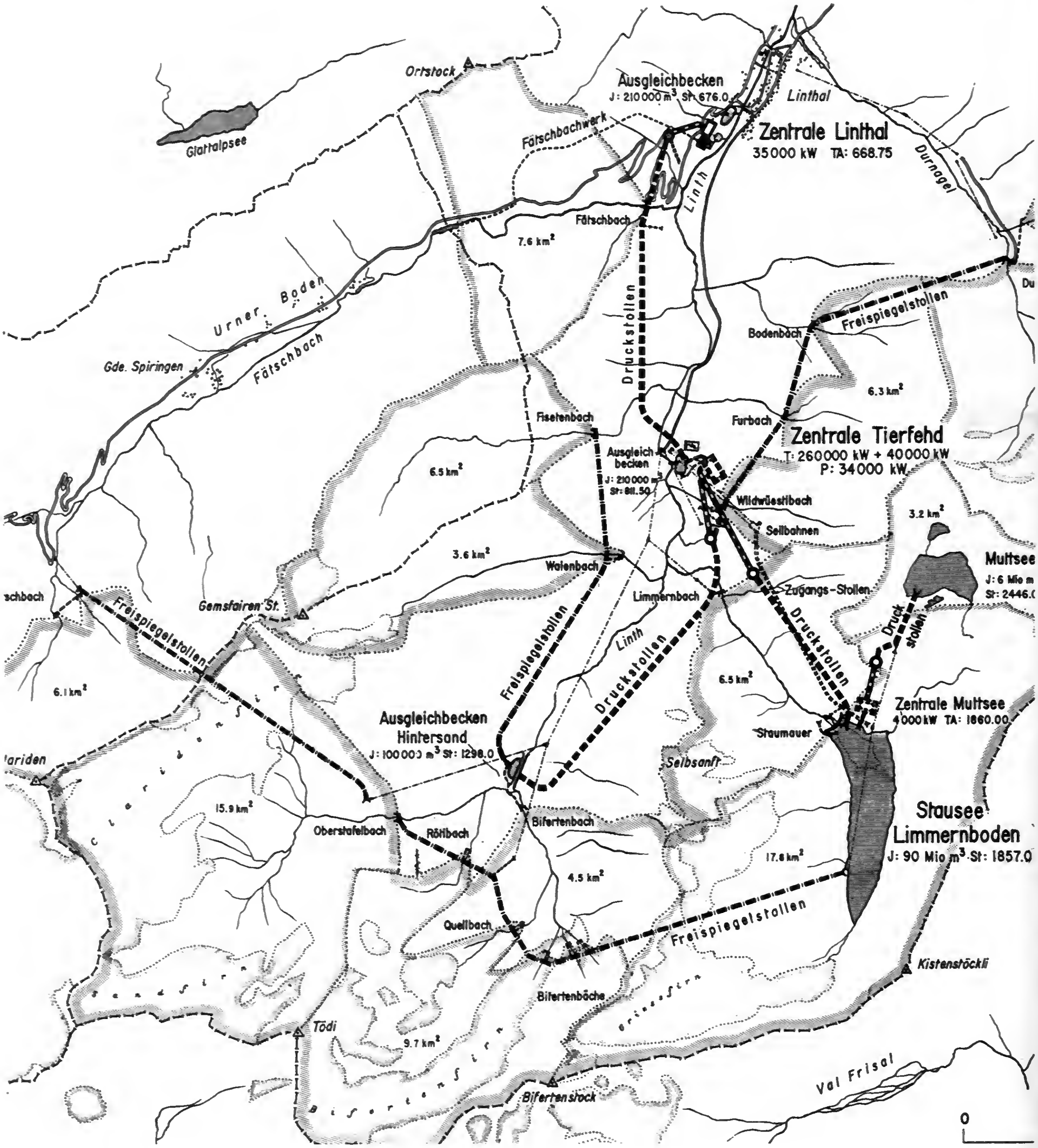



Fig. 25.1 - Kraftwerk Lith-Limmern System

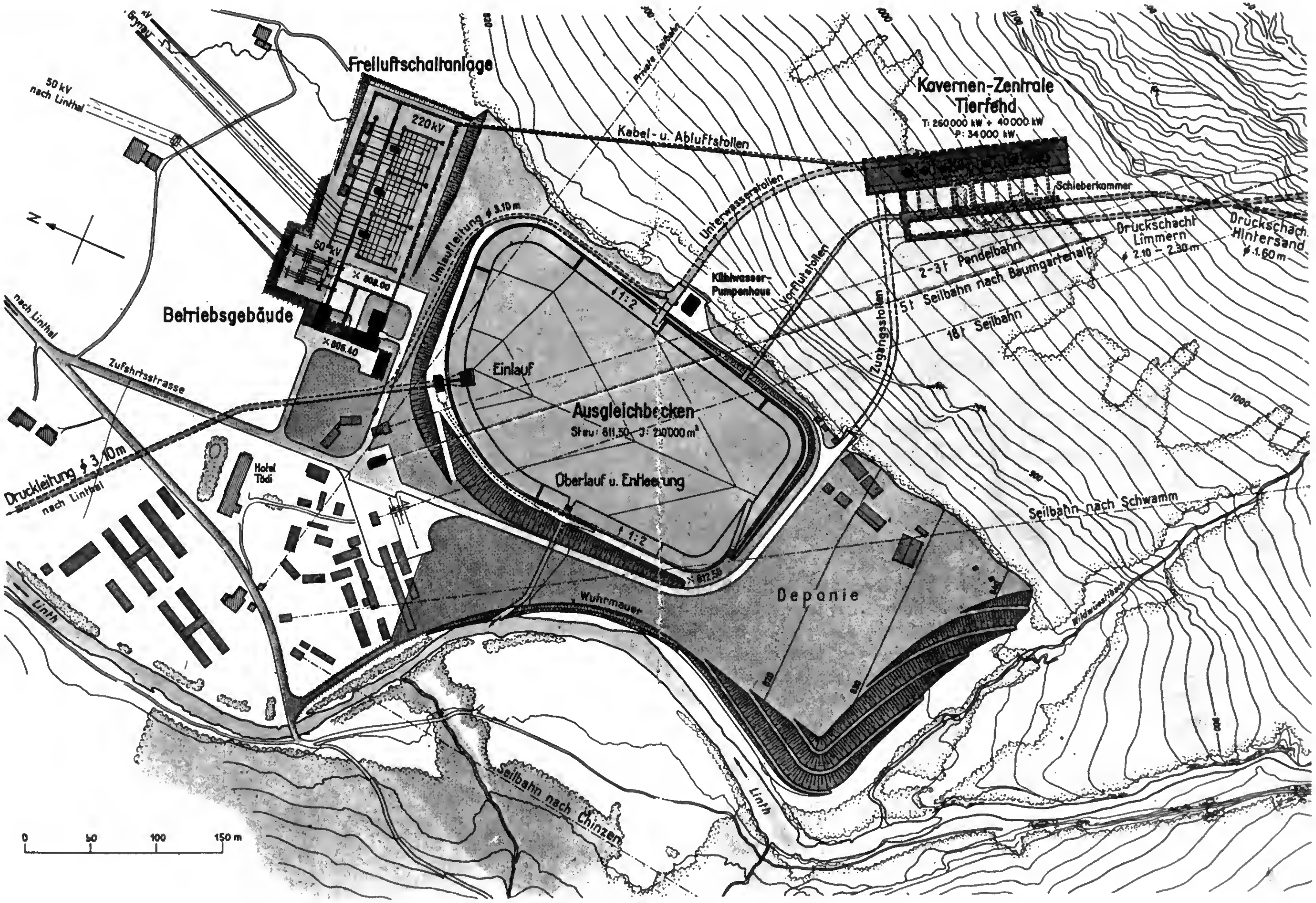



Fig. 25.2 - Location Map of Tierfehd Station

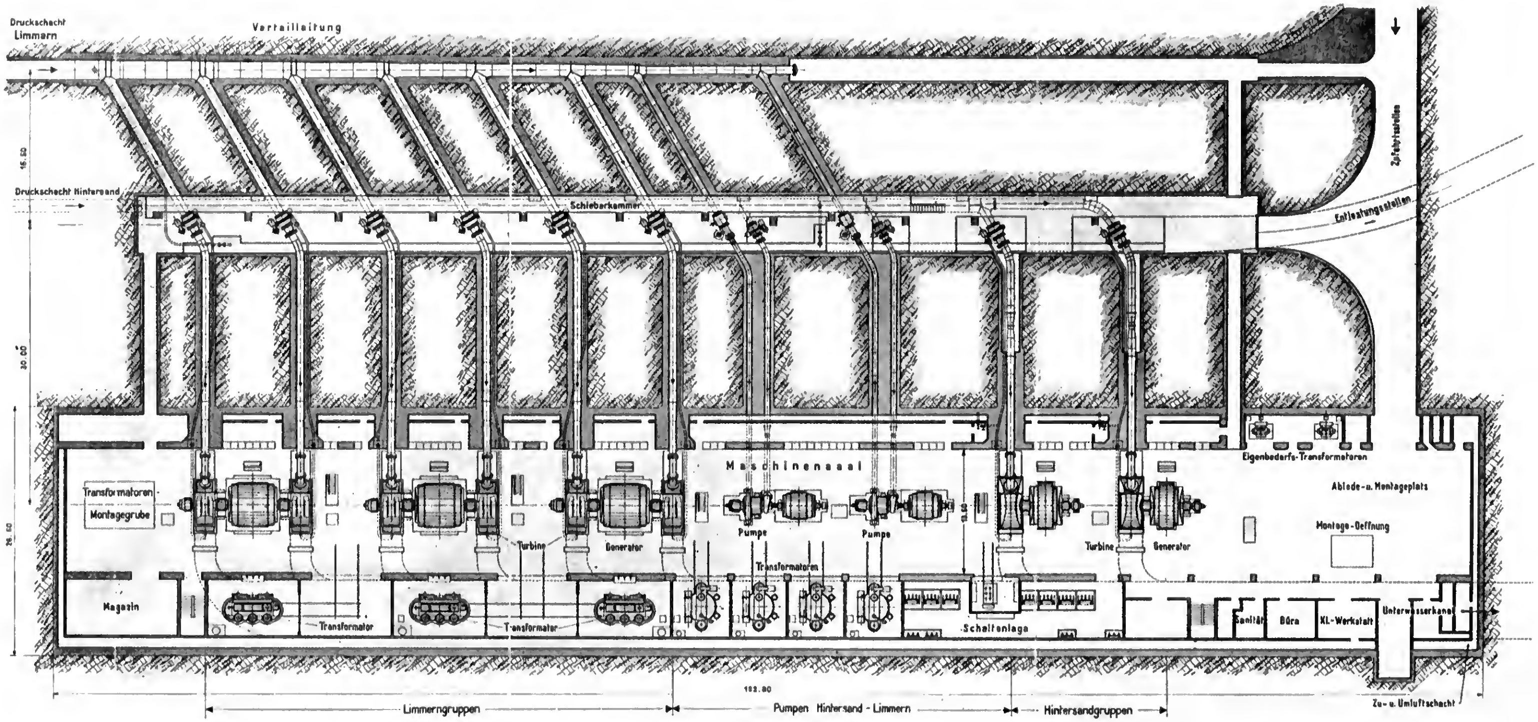



Fig. 25.3 - Plan of Pump and Turbine Station.

Fig. 25.4 (H 17) View of Afterbay

Fig. 25.5 - Plant Entrance

Fig. 25.6 (H 7A) View of Driver

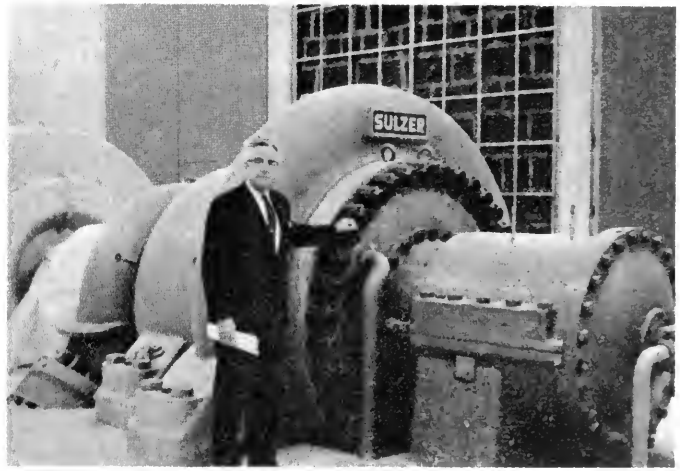



Fig. 25.7 (H 4A) O.B. end of Pump

Fig. 25.8 (H 3A) Plant Interior

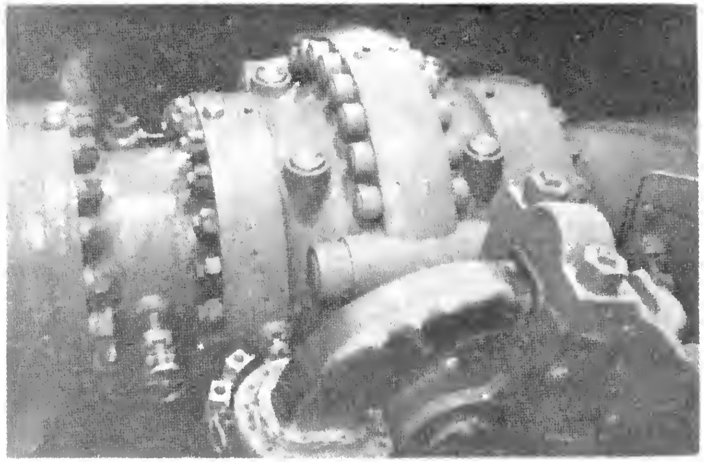


Fig. 25.9 (H 11A) Turbine Inlet Valve

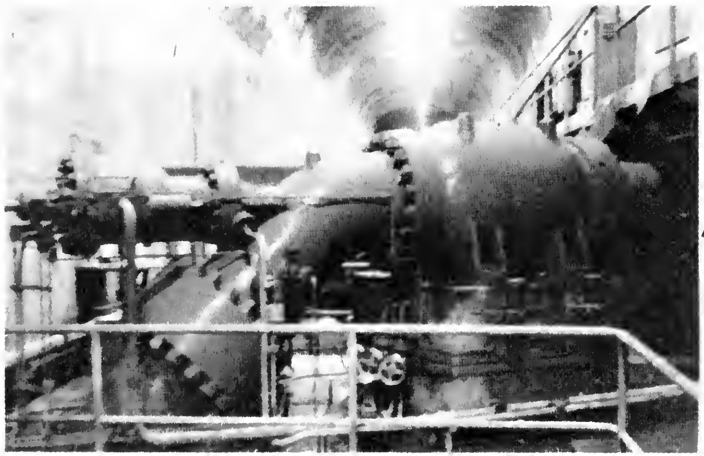


Fig. 25.10 (H 9A) Pump Inlet Valve

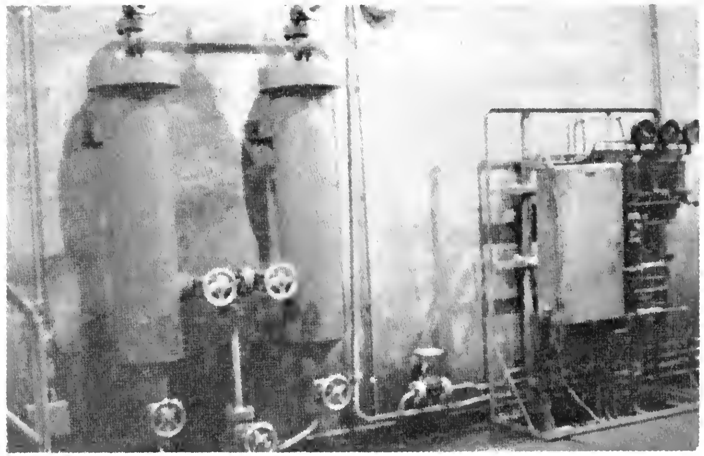


Fig. 25.11 (H 12A) Valve Water Sediment Collector

## Vibration Records

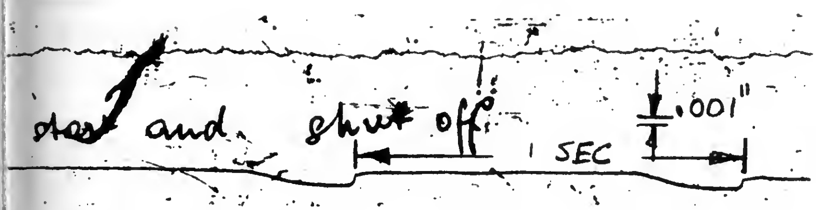
Kraftwerke Linth Limmern A. G. Linthal, Glarus, Switzerland

Plant : Tierfehd (underground power house)

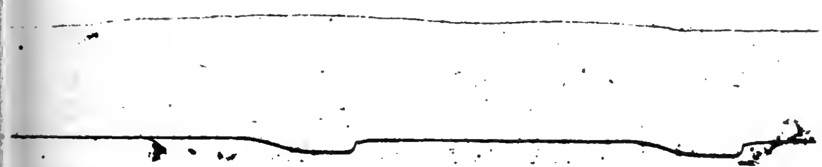
Units : two, 3-stage, single flow, horizontal pumps;
22,800 HP, 97 cfs, 1775 ft, 1000 RPM.

Records taken : September 11, 1964

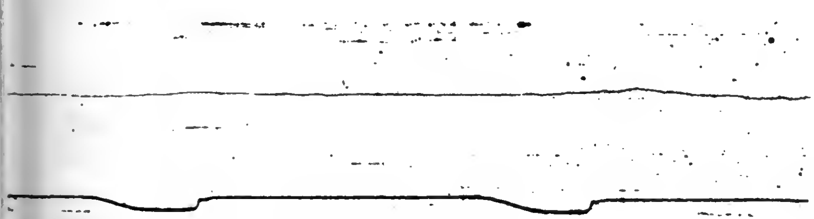
Pump #1



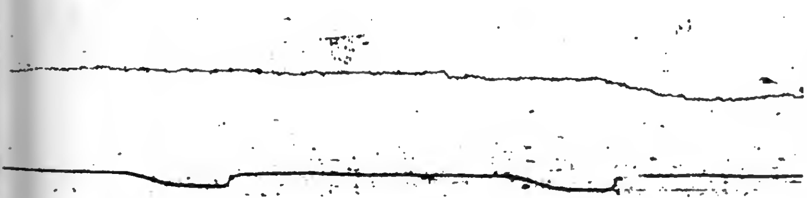

1. Middle bearing during start with discharge valve closed



2. Volute - normal pumping



3. Shut down - valve closing



4. 80% closed

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 9000 | .0003 |
| ---- | less than .0002 |
| ---- | less than .0002 |
| 8400 | .0002 |

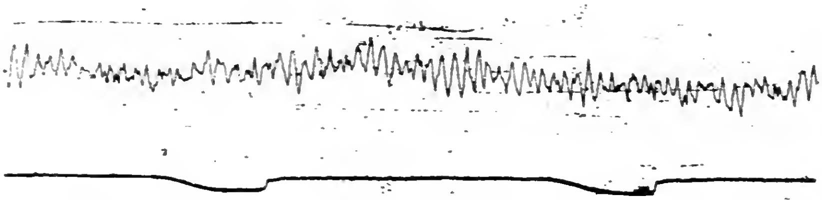
Figure 25-12

## Vibration Records (cont.)

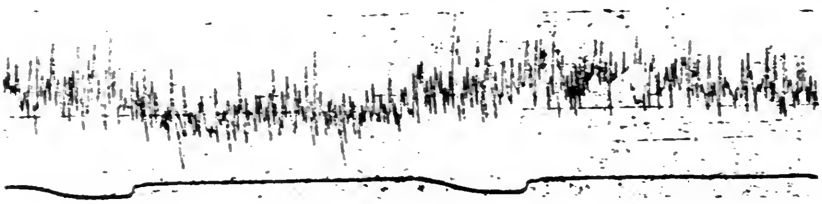
Kraftwerke Linth Limmern A. G. Linthal, Glarus, Switzerland

Plant: Tierfehd (underground power house)

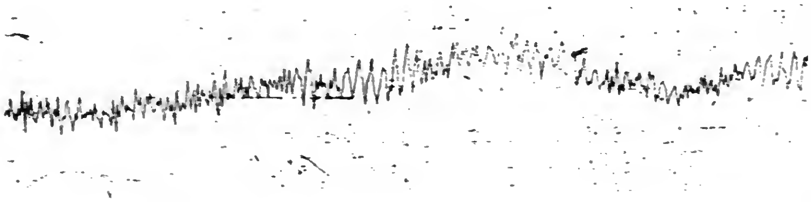
Vevey Turbine



1. Point #1



2. Point #2



3. Point #3

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 3900 | .0025 |
| 4800 | .0026 |
| 6300 | .0025 |

Figure 25-13

PLANT NAME: SIPPLINGEN

REPORT NO.: 26

| | |
|---|---|
| LOCATION-ALTITUDE: | North Shore of Lake Constance, Germany - 1280' |
| OWNER: | Zweckverband Bodensee Wasserversorgung |
| ADDRESS: | Vaihingen-Hauptstrasse 163 |
| TYPE OF PLANT: | Surface-pumping (only) |
| SERVICE | Domestic water supply to Stuttgart and intermediate communities. |
| TYPE OF WATER: | Clear, Cold lake water |
| UNITS INSTALLED: | Six horizontal, single-suction, 2 stage, "Back-to-Back", pumps. |
| HORSEPOWER: | 2 x 8600 HP 4 x 3750 HP |
| CFS: | 2 x 53 4 x 26.5 (Total 212 cfs) |
| STATIC HEAD: | 1020' |
| PLANT STARTED: | October 1958 |
| VISITED BY: | Cole - Hartmann |
| DATE: | 9/15/64 |
| PERSON(S) INTERVIEWED & TITLE(S): | A. Reiter, Chief Operator |

REMARKS: Station delivers lake water to filter station at Sipplingerberg. From there, pressure is boosted another 224' to 410" (depending on flow) and delivered north through a 103 mile pipeline which terminates near Stuttgart. Pipeline capacity 74 cfs, 35% of pump station capacity.

PUMPS:

| | | |
|---|---|---|
| TYPE: | Two-Stage Horizontal "Back-to-Back" | |
| MANUFACTURER: | Voith (Heidenheim) | |
| SIZE DISCHARGE: | 27.5" | 19.65" |
| SIZE SUCTION: | 31.5" | - |
| RPM: | 998 | 1490 |
| CFS: | 53 | 26.5 |
| HEAD: | 1000'-1035' | 1000'-1035' |
| H.P. REQUIRED: | 6720-6950 | 3375-3500 |
| N s.: | 1430 | 1532 |
| INSTALLED: | October 1958 | |
| HRS. OF OPERATION | I - 9129; II- 9777; III- 9648; IV - 9991; V - 9869; VI- 8771 | |
| MIN. SUBMERGENCE: | - 0.3' | |
| NORMAL SUBMERGENCE: | + 4' | |
| MAX. SUBMERGENCE: | + 7' | |
| REMARKS: | Pumps start and operate smoothly, but with excessive cavitation, which has shown up in damage to the impellers. This condition was recognized from the beginning, but it was felt that it would be more economical to repair or replace impellers periodically than lower the plant to provide adequate submergence to prevent cavitation. | |

EFFICIENCIES:

| | | |
|---|---|---|
| MODEL GUARANTEE: | No Model | |
| MODEL ACTUAL: | No Model | |
| PROTOTYPE-GUARANTEED: | No Information | |
| PROTOTYPE-ACTUAL: | 89.5 | 89.0 |
| METHOD OF TEST: | No Test | |

CONSTRUCTION DETAILS:

| | | |
|---|---|---|
| DIAMETER DISCHARGE: | 27.5" | 19.65" |
| DIAMETER IMPELLER: | 25.6 | |
| DIAMETER EYE: | - | |
| DIAMETER SHAFT: | | |
| MATERIAL CASING: | Cast Steel | Cast Iron |
| MATERIAL IMPELLER: | Cr. Steel | Cr. Steel |
| MATERIAL IMPELLER RINGS· | None | None |
| MATERIAL-CASING RINGS: | Cast Iron | Cast Iron |
| RADIAL CLEARANCE: | 0.3 mm | 0.3 mm |
| MATERIAL BALANCING RINGS: | None | None |
| MATERIAL INTERSTAGE SEAL: | Babbitt | Babbitt |
| RADIAL CLEARANCE: | - | - |
| MATERIAL DIFFUSER: | Bronze | Bronze |
| BEARING: | - | - |
| THRUST BEARING: | Fixed Segments | |

| | |
|---|---|
| TYPE OF PACKING: | Labyrinth and packed stuffing Box |
| MATERIAL OF PACKING: | Babbitt Labyrinth plus Teflon - Asbestos - "Chempac" |
| MATERIAL OF SLEEVE: | Stainless Steel |
| CLEARANCE: | - |
| REMARKS: | Back-to-back construction. Hydrostatically balanced. |

## MOTOR OR GENERATOR:

| | | |
|---|---|---|
| TYPE: | Asynchronous - Horizontal | |
| MANUFACTURER: | Brown Boveri | Siemans |
| H. P.: | 7000 | 3500 |
| R. P. M.: | 998 | 1490 |
| VOLTAGE: | 6000 | 6000 |
| STARTING: | With Rheostat | Direct |
| REMARKS: | Units I and IV (7000 HP) are of the wound rotor type and start with Rheostat. Small units have induction type motors which start across the line. | |

## TURBINE:

| | |
|---|---|
| TYPE: | None used. |
| MFG.: | |
| HEAD: | |
| R. P. M.: | |
| H. P.: | |
| REMARKS: | |

VALVES:

| | | |
|---|---|---|
| INTAKE | - | - |
| TYPE: | Butterfly | Butterfly |
| MANUFACTURER: | Bopps & Reuther | |
| SIZE: | 31.5 | |
| OPERATION: | Manually | |
| DISCHARGE: | | |
| TYPE: | Needle | Needle |
| MANUFACTURER: | Voith | Bopps & Reuther |
| SIZE: | 27.5" | 19.6" |
| OPERATION: | | |
| OPENING: | Oil-Hydro. | Mechanically |
| CLOSING: | Water | Mechanically |
| TIME OF CLOSING: | | |
| NORMAL: | | |
| EMERGENCY: | 3 sec. | |
| REMARKS: | | |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | 2 x 4.28' |
| LENGTH: | 11,500 ft. |

| | |
|---|---|
| MATERIAL: | Steel |
| TYPE OF UPPER GATE: | |
| SURGE TANK: | None |
| REMARKS: | Discharges direct into filters - Surge protection, provided by Flywheel on large pumps - Hydraulically operated by-pass on small pumps. |

WATER QUALITY:

| | | | |
|---|---|---|---|
| GENERAL: | Pure clean lake water. | | |
| Ph: | 7.8 | SOLIDS: | None |
| HARDNESS: | C.7 Total 9.10 dH | SALINITY: | None |
| REMARKS: | Water contains minute quantity of Algae particles - Temperature remains 37° - 39°F throughout the year. | | |

## MAINTENANCE AND OPERATION:

| | | |
|---|---|---|
| OPERATING SCHEDULE: | Large pump 20 Hrs./day. Small on peak - alternated. | |
| STARTS/DAY: | 1/Day | 2/Day |
| HOURS OF OPERATION: | I - 9129; II - 9777; III - 9648; IV - 9991; V - 9869; VI - 8771 | |
| UNPLANNED OUTAGES: | None | |
| CAUSE: | - | |
| INSPECTION SCHEDULE: | 1960 - 1963 - Next 1965 | |
| TIME REQUIRED: | 6 Hours | |
| OVERHAUL SCHEDULE: | Expect 1st overhaul soon. | |
| TIME REQUIRED: | | |
| IMPELLER CAVITATION: | Severe. | |

| | | |
|---|---|---|
| SEAL RING WEAR: | None | |
| NOISE LEVEL-START: | - | A - 90 + 5 |
| NOISE LEVEL-RUN: | A - 90 + 5<br>B - 100 - 3.5<br>C - 100 - 3.5 | A - 90 + 3.5 |
| VIBRATION: | None (See Charts) | |
| REMARKS: | Original stuffing Box Packing was British lead - Lamell (Vemeet). Lead broke after one year. Replaced by (U.S.) Chempac - OK after two years.<br><br>Impellers show cavitation damage. Expect to repair in place at end of 10,000 hr. guarantee period (soon). | |

## GENERAL REMARKS

The Sipplingen pumping scheme consists of two plants:-

The lower one is the Sipplingen Seepumpwerk (Lake pumping plant), which pumps the water out of the lake of Konstanz up to a head of more than 300 m. This is the plant we have visited. From there the water is pumped by the plant Sipplingen Berg (mount Sipplingen) through a penstock 22 km long and 1.3 m diameter to a free level reservoir from which the water goes in a pressure pipe some 200 km to Stuttgart. The static head of the upper plant is only some 60 m but the total pumping head goes up to a 125 m due to friction. There are three different means of surge control applied to this scheme:-

In the lower plant the small pumping units have no additional flywheels, but an over pressure relief valve. There is no danger of dynamic under pressure according to the penstock profile. The bigger units have additional flywheels for surge control which take also care of the surge control for the combined operation of the bigger units together with the smaller ones. The pressure relief valve is operating only when the smaller units run alone. In the Sipplingen Berg station we have a case of a very long penstock similar to some American installations. For surge control, air tanks are used. This may indicate that also in Europe other means than flywheels are used for surge control depending on the various conditions.

The pumps show heavy cavitation noise and according to operating personnel, considerable cavitation damage on the impellers. The submergence of these pumps is extremely small and according to Voith, cavitation was expected from the beginning. Considering the size of the building and comparing the additional costs for lower setting with the very small and cheap pump impellers, it seems quite clear that in this case the cavitation is the economical solution. Due to the more than 100% over-capacity they have installed, there is no difficulty to exchange or repair impellers. The over-capacity was installed for safety reasons. The plant consists of two equal halves which are hydraulically completely separated from each other. Even catestrophic events like a penstock rupture would effect only one half of the plant. Thus, even in the worst case the plant can still operate with rated capacity. The purpose was to ensure 100% water delivery under all circumstances. It may be of special interest for Tehachapi how serious the safety requirements were taken in this case.

The water is chlorinated in the Sipplingen Berg plant after filtration. Chlorination at Sipplingen Berg is 0.6 ppm, minimum chlorination at delivery to consumption points is 0.2 ppm.

The pumps at Sipplingen Berg are of the single stage, double flow type, KSB*) Frankenthal/Germany manufacture, and have the following rating:-

| Unit | Flow | Head | Speed |
|---|---|---|---|
| I | 750 l/s | 68 m | 1000 rpm |
| II | 1500 l/s | 80 m | 1000 rpm |
| III | 2100 l/s | 100 m | 750 rpm |
| IV | 3000 l/s | 125 m | 750 rpm |

*) Klein, Schanzlin & Becker

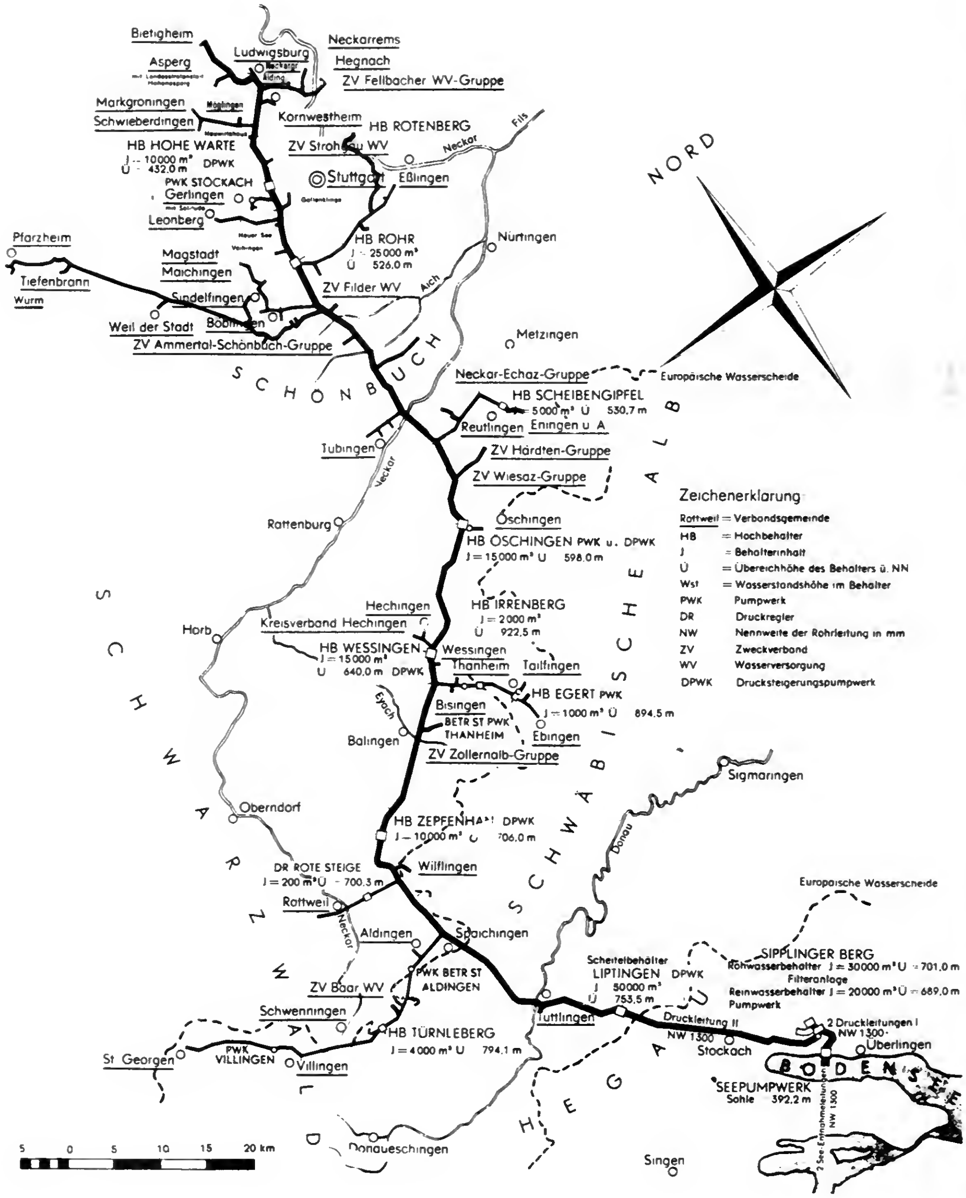
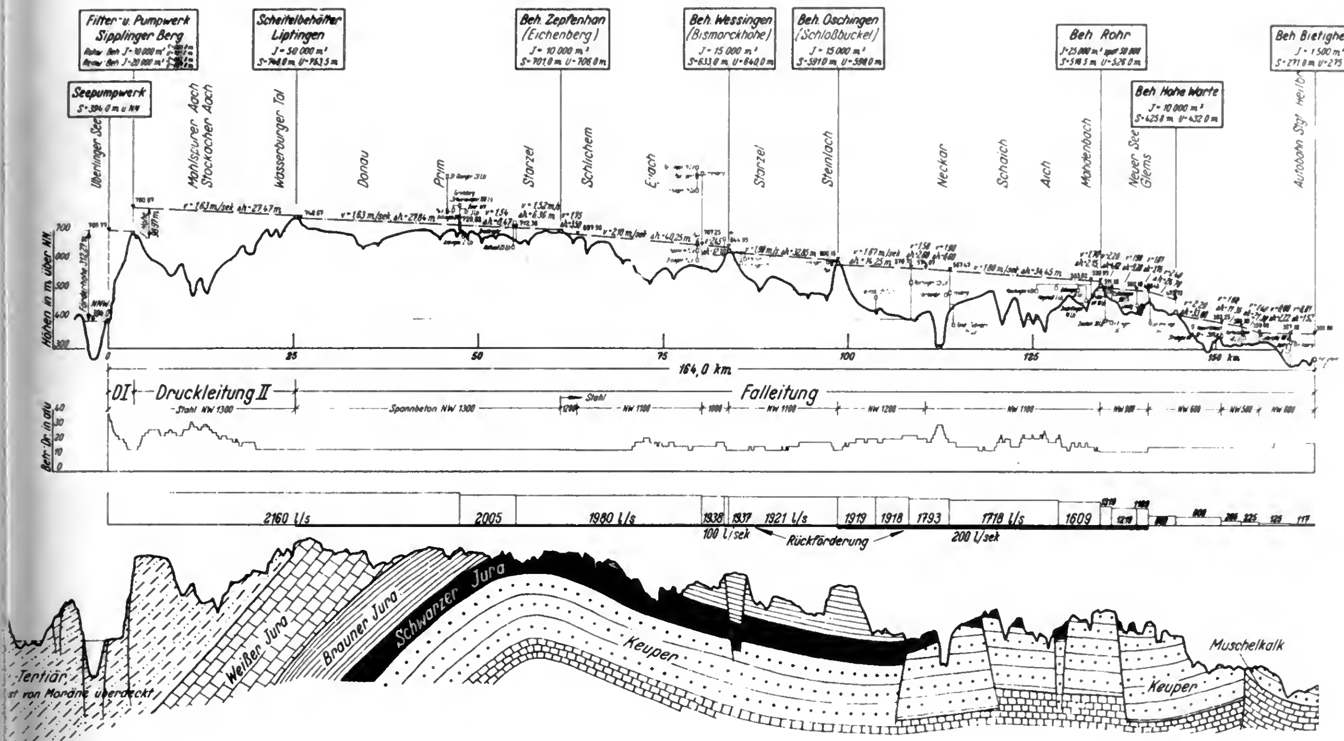



Fig 26-1

PLAN OF WATER WORKS SYSTEM




ig. 26-2 Profile of Supply System

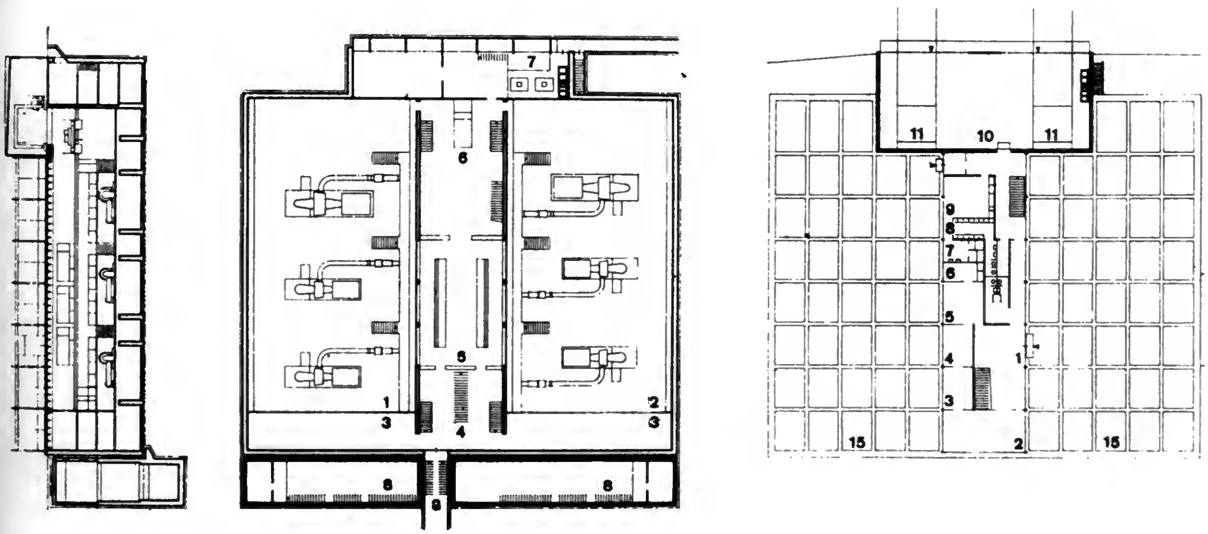


Fig. 26-3 Plan and Sectior of Pumping Plant

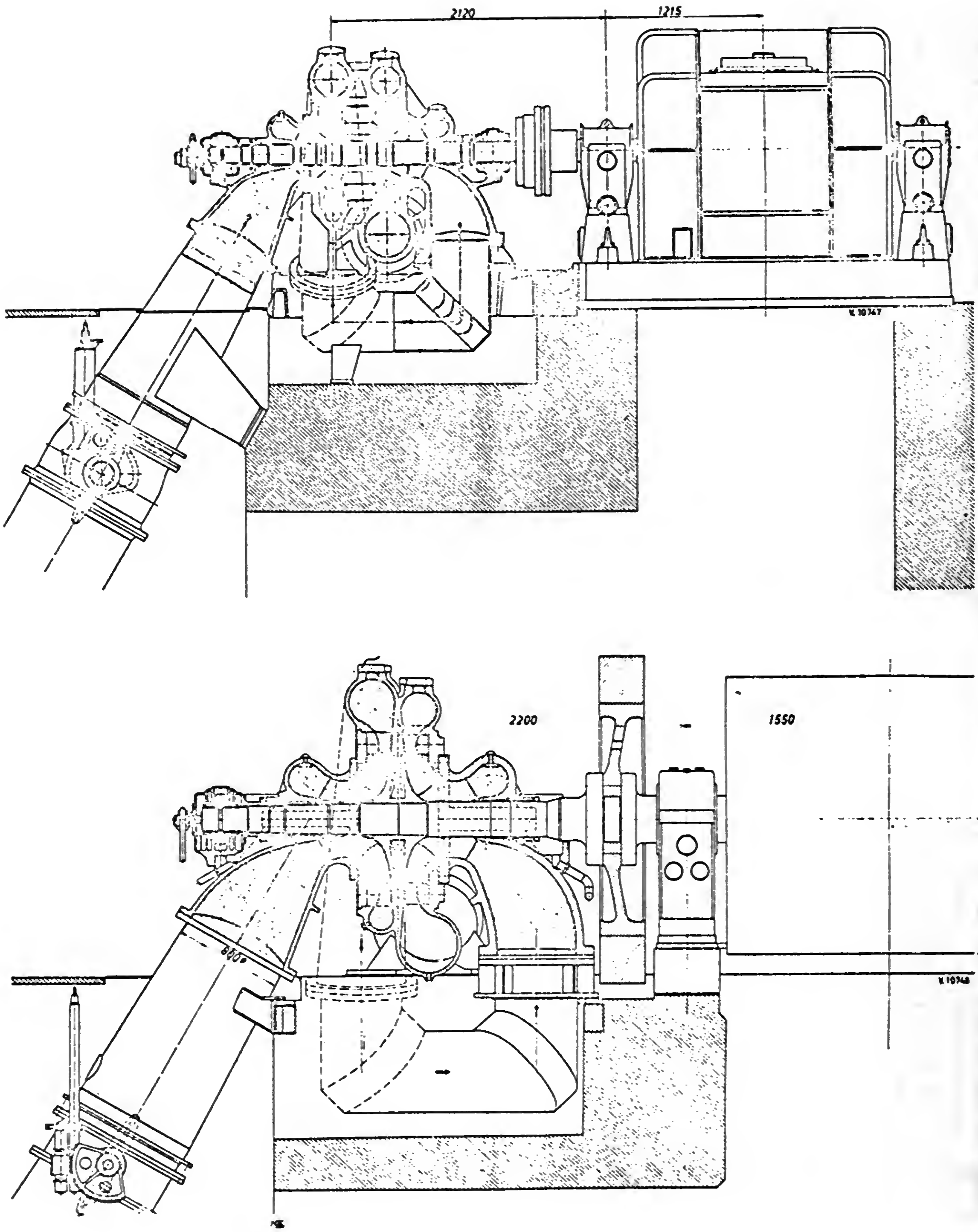



Fig. 26.4 - Section of Sipplingen Pumps

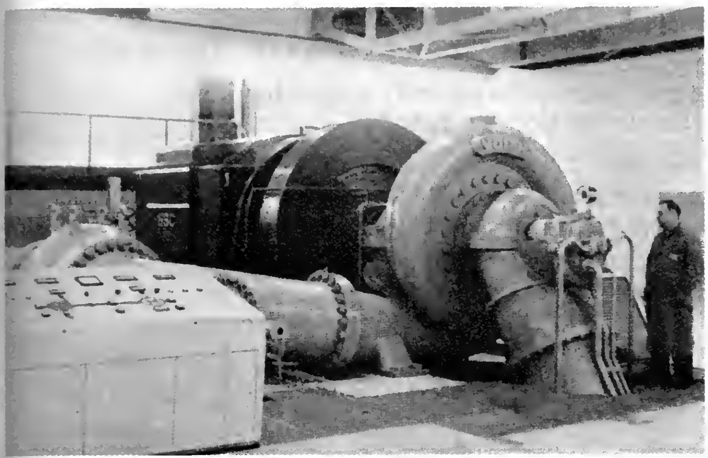


Fig. 26-5

53 CFS Unit
Showing Flywheel

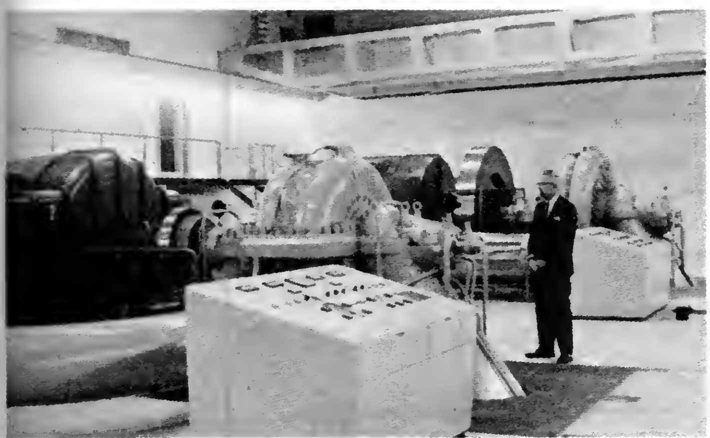


Fig. 26-6

One large and one small
unit - Control Cabinets

Fig. 26-7

View of one large and
one small unit in one-half of the plant. Duplicate half beyond wall
at left.

## Vibration Records

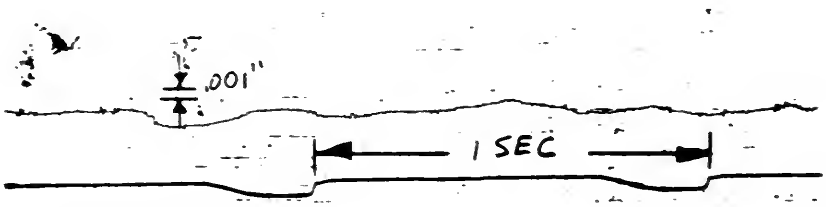
Zweckverband Bodensee Wasserversorgung, Stuttgart, Germany

Plant : Sipplingen (Seepumpwerk) (surface power house)

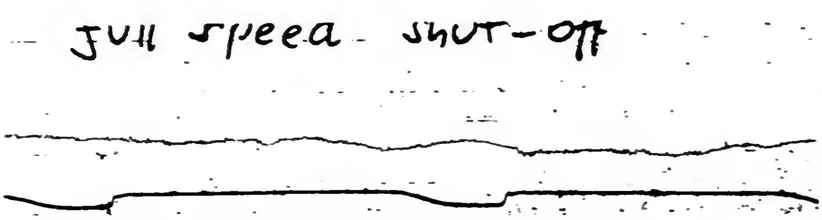
Units : two (units 1 and 6), 2-stage, single flow, back-to-back, vertical pump
8600 HP, 53 cfs, 1018 ft, 1490 RPM.
four (units 2 - 5), 2-stage, single flow, back-to-back, vertical pumps
3750 HP, 27 cfs, 1018 ft, 990 RPM.

Records taken: September 15, 1964

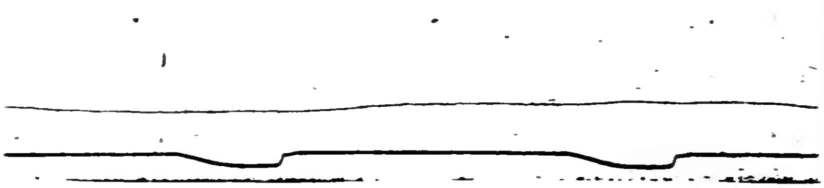
Unit III, Small Pump, Volute



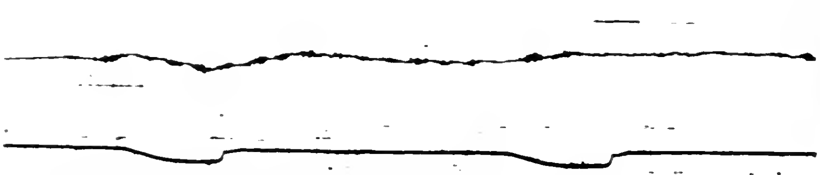

1. Pump start




2. Full speed with discharge valve closed



3. Volute, normal pumping



4. Discharge pipe near pump

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 4900 | .0003 |
| 6000 | .0003 |
| ---- | less than .0002 |
| 10,500 | .0004 |

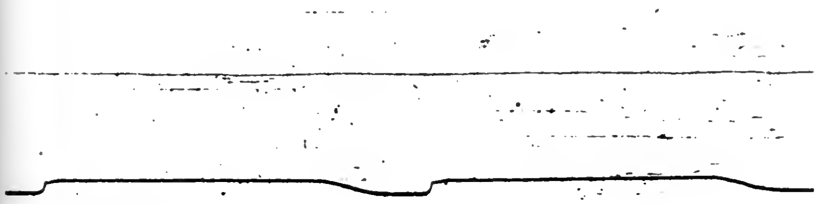
Figure 27-8

## Vibration Records (cont.)

Zweckverband Bodensee Wasserversorgung, Stuttgart, Germany

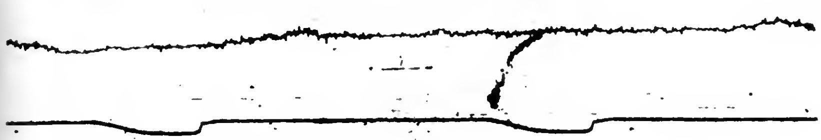
Plant : Sipplingen (Seepumpwerk) (surface power house)

Unit I Big Pump - Normal Pumping



5. Volute

pipe after valve



6. Discharge Pipe after valve

| | Frequency c.p.m. | Average Amplitude inches |
|---|---|---|
| 5. Volute | ---- | less than .0002 |
| 6. Discharge Pipe after valve | 9000 | .0004 |

Figure 27-9

PLANT NAME: COTILIA

REPORT NO.: 27

| | |
|---|---|
| LOCATION-ALTITUDE: | CENTRAL ITALY - 1290' |
| OWNER: | E. N. E. L. (Ente Nazionale Energia Electrica) |
| ADDRESS: | (Nationally owned Power Corp.) ROME |
| TYPE OF PLANT: | Underground - Horizontal Units |
| SERVICE | Power Supply for Italy |
| TYPE OF WATER: | Clean River Water |
| UNITS INSTALLED: | Two Single-Stage, Double-Suction, Turbine Generator Pump Units |
| HORSEPOWER: | 30,000 KW - 40,000 HP - 375 RPM |
| CFS: | 495 - 672 |
| STATIC HEAD: | 480' |
| PLANT STARTED: | Turbines 1940- Pumps 1946 |
| VISITED BY: | Lutz - Cole |
| DATE: | September 22, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Trivellone Giacinto, General Manager |

REMARKS: Plant operates as Pump Storage in the Spring when there is an abundance of power in Northern Italy -- other times as power generation.

Pumps take water from two Rivers; one 18 $M^3$/ SEC pure clean artisian water, and the other variable - clean except when raining - sedimentation system catches all sand.

PUMPS:

| | | | |
|---|---|---|---|
| TYPE: | Sgl. Stage - Dbl. Suction (Horizontal) | | |
| MANUFACTURER: | 1) | ESCHER WYSS - TOSI | |
| SIZE DISCHARGE: | | 71" (1800 mm) | |
| SIZE SUCTION: | | 2 x 67" (1700 mm) | |
| RPM: | 2) | 375 (337.5) | |
| CFS: | | 495 - | 672 |
| HEAD: | | 492 - | 262 |
| H.P. REQUIRED: | | 31,800 - | 23,000 |
| N s.: | | 1210 - | 2240 |
| INSTALLED: | | 1946 | |
| HRS. OF OPERATION | | I- 17,000 | II- 14,000 |
| MIN. SUBMERGENCE: | 3) | 29.5' (9 MTS) | |
| NORMAL SUBMERGENCE: | | 32.8' (10 MTS) | |
| MAX. SUBMERGENCE: | | 32.8' (10 MTS) | |

REMARKS:

1) Tosi at Terni built heavy cast steel parts and shaft. E-W furnished internal parts.

2) Original speed 337.5 - changed to 375 in 1949 when frequently changed from 45 to 50.

3) Pumps stop automatically when submergence falls below 9.0 MTS.

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | Not Known |
| MODEL ACTUAL: | 82 - 83% (Approx.) |
| PROTOTYPE-GUARANTEED: | Not Known |
| PROTOTYPE-ACTUAL: | 87% (per E-W) |
| METHOD OF TEST: | Test made years ago with propeller type meter in suction. |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 71" |
| DIAMETER IMPELLER: | 1) 333 RPM 106.7" - 375 RPM - 107.3" |
| DIAMETER EYE: | 67" $\pm$ |
| DIAMETER SHAFT: | 18.6" $\pm$ |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | Bronze |
| MATERIAL IMPELLER RINGS: | Bronze |
| MATERIAL-CASING RINGS: | 2) Cast Iron (CR Ni) |
| RADIAL CLEARANCE: | 1 mm |
| MATERIAL BALANCING RINGS: | None |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | Bronze |
| BEARING: | 18.6" x 12" $\pm$ |
| THRUST BEARING: | Kingsbury tupe 28.8" O. D. |

TYPE OF PACKING: Originally Jute - Graphita

MATERIAL OF PACKING: Changed to Carbon Rings

MATERIAL OF SLEEVE: 3) Bronze (lasts 17, 000 hrs.)

CLEARANCE:

REMARKS:
1) Impeller changed on unit No. I when frenquently changed. No. II always 50 cycles.
2) Original rings rubbed - changed in 1953 & 1954 to stainless -- casing rings to steel.
3) Clean water applied to stuffing box.

MOTOR OR GENERATOR:

TYPE: Horizontal - Synchronous - Direct driven exciter outside of turbine.

MANUFACTURER: I- Brown Boveri II- CGE

H.P.: 30, 000 KW

R.P.M.: 375

VOLTAGE: 10, 000

STARTING: 1) Start by Turbine

REMARKS: 1) Originally designed for low voltage starting with 50% taps on transformer. Tried once and then low voltage system dismantled.

TURBINE:

TYPE: Horizontal - Francis

MFG.: I- TOSI II- San Geirgio

HEAD: 480'

R.P M.: 375

H.P.: 40, 500

## VALVES:

### INTAKE:

| | |
|---|---|
| TYPE: | 2 - Rotary |
| MANUFACTURER: | Riva |
| SIZE: | 67" each |
| OPERATION: | Oil Pressure (Hand) |

### DISCHARGE:

| | |
|---|---|
| TYPE: | Needle |
| MANUFACTURER: | TOSI |
| SIZE: | 71" |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | Water from Penstock |
| TIME OF CLOSING: | |
| NORMAL: | 57 cm. in 5 sec.<br>5 cm. in 4 sec. |
| EMERGENCY: | Same |
| REMARKS: | No auxilliary seat. Have to empty Penstock to repair: |

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | 2 - 13.1" (4 MTS) |
| LENGTH: | 785' - (280 MTS) |

| | |
|---|---|
| MATERIAL: | Reinforced Concrete |
| TYPE OF UPPER GATE: | Gate |
| SURGE TANK: | None |
| REMARKS: | |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Clear and Clean |
| Ph: | Unknown - Solids Nil |
| HARDNESS: | Quite hard |
| REMARKS: | Very good water |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | In Spring only |
| STARTS/DAY: | Two during season |
| HOURS OF OPERATION. | I- 17,000 II- 14,000 |
| UNPLANNED OUTAGES: | Two (1953 and 1964) |
| CAUSE: | Discharge valve repairs |
| INSPECTION SCHEDULE: | Every six months |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | None |
| TIME REQUIRED: | - |
| IMPELLER CAVITATION: | A little (corrected in 1964). |

| | | |
|---|---|---|
| SEAL RING WEAR: | 1) | 0.8 mm in 8000 Hrs. |
| NOISE LEVEL-START: | | - |
| NOISE LEVEL-RUN: | | - |
| VIBRATION: | | - |
| REMARKS: | | Could not start pump for observation. |
| | 1) | Seal rings changed in 1953 and 1964. Stainless steel rings installed. |

Sr. Trivellone:

"LA MACCHINE SONDO COME
LA DONNE - MOLTA GIOLA
E MOLTI DOLORI"

(The machine is like a woman -- much joy and much pain).

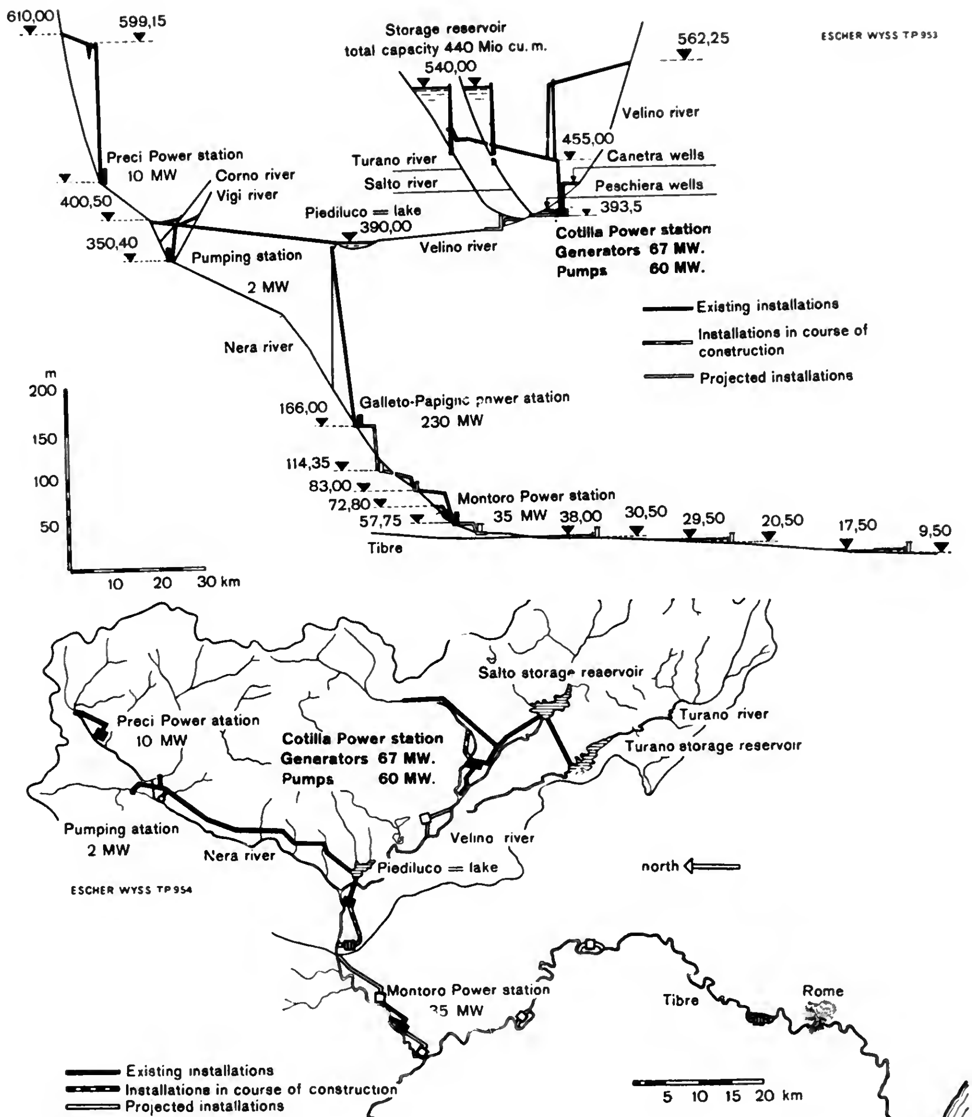



Fig. 27.0 - Plan and Profile of Velino-Nera System

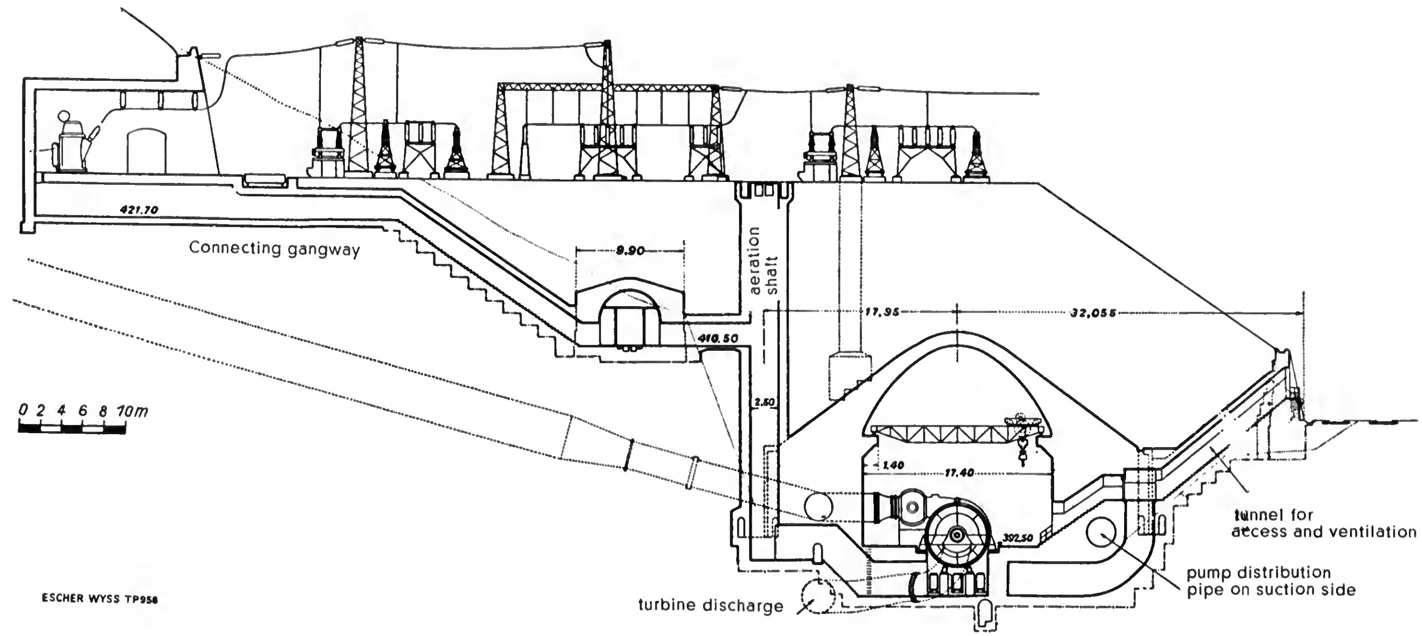



Fig. 27. 1 - Elevation of Station

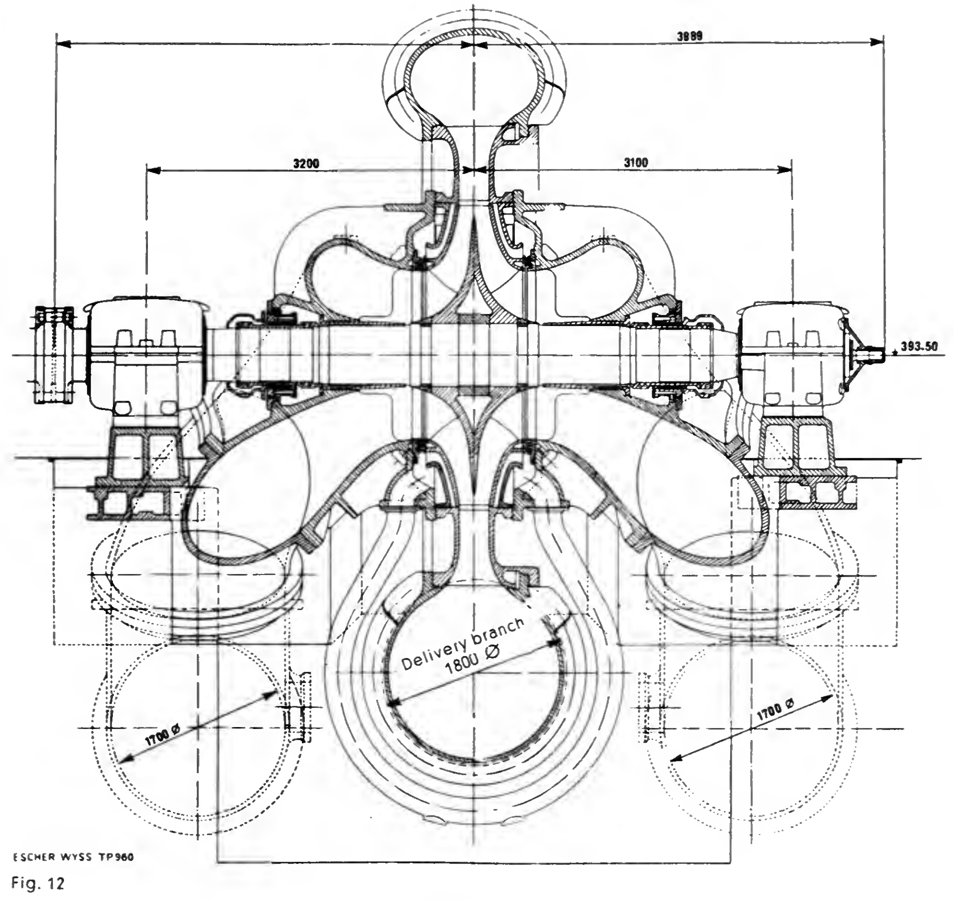



Fig. 27. 2 - Section through Pump

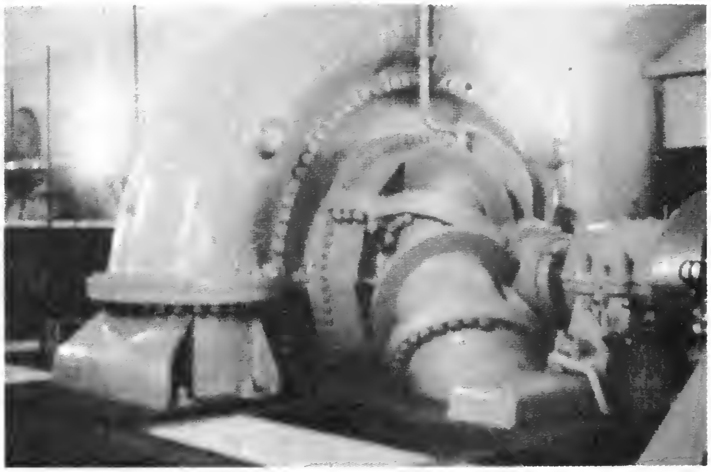


Fig. 27.3
Close-up of Pump

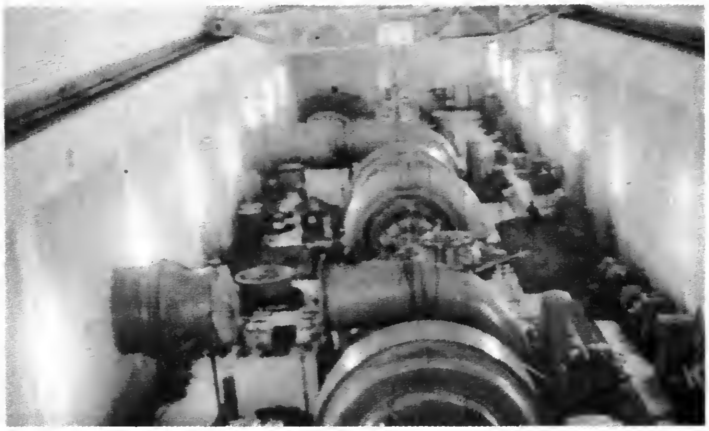


Fig. 27.4
View of Interior

Fig. 27.5
Pump Impeller

Fig. 27.6
Diffusor

PLANT NAME: PROVVIDENZA

REPORT NO.: 28

| | |
|---|---|
| LOCATION-ALTITUDE: | Central Italy - 3400' |
| OWNER: | Ente Nazionale Energia Electrica |
| ADDRESS: | Rome |
| TYPE OF PLANT: | Underground - Horizontal Units |
| SERVICE | Electric Power to Italy |
| TYPE OF WATER: | Clean - Clear |
| UNITS INSTALLED: | Two horizontal, 2-stage, double suction turbine - pump generator sets. |
| 1) | One Vertical, reversible pump turbine set. |
| HORSEPOWER: | 3 x 62,700 HP (500 RPM) 1 x 87,000 HP (375 RPM) |
| CFS: | 2 x (438 to 565) 1 x 600 |
| STATIC HEAD: | 870' |
| PLANT STARTED: | I- 1949; II- 1953; III- 1962 |
| VISITED BY: | Cole - Lutz |
| DATE: | September 23, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Sr. Crescentini, Gen. Manager<br>Enrico Pennacchi, Shift Foreman<br>Alfred D'Aurizio, Deputy Chief of Station |
| REMARKS: 1) | Vertical unit used as s turbine unit only. |

PUMPS:

| | |
|---|---|
| TYPE: | Two - Horizontal Double-suction - 2-stage |
| MANUFACTURER: | I- Escher Wyss - Tosi<br>II- Escher Wyss - Terni III- Allis Chalmers |
| SIZE DISCHARGE: | 67" (1700 mm) |
| SIZE SUCTION: | 2 x 59" (1500 mm) |
| RPM: | 500 (III - 375 RPM) |
| CFS: | 438 to 565 (III - 600) |
| HEAD: | 940 to 790 |
| H.P. REQUIRED: | 33,500 to 58,000 (III- 65,000) |
| N s.: | 1549 to 2010 |
| INSTALLED: | I - 1949; II- 1953; III- 1962 |

| HRS. OF OPERATION | | I | II | III |
|---|---|---|---|---|
| | Generator | 44,726 | 24,623 | 4180 |
| | Pump | 24,543 | 12,820 | 928 |

| | |
|---|---|
| MIN. SUBMERGENCE: | 98.4' |
| NORMAL SUBMERGENCE: | 98.4' |
| MAX. SUBMERGENCE: | 105' |
| REMARKS: | Pump room large and spacious - 52.5' wide x 394' long. Access tunnel 2300' long at 6% grade. Plant has separate drainage tunnel at 1% grade. |

## EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | Not known |
| MODEL ACTUAL: | 86% + |
| PROTOTYPE-GUARANTEED: | Not Known |
| PROTOTYPE-ACTUAL: | 90.9% (per E-W) |
| METHOD OF TEST: | 25 current meters in suction pipes |

## CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 67" (1700 mm) |
| DIAMETER IMPELLER: | 81.5" (86.2" at 45 cycles) |
| DIAMETER EYE: | 52" ± |
| DIAMETER SHAFT: | 20.4" to 32.2" (Flange) |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | Cast Steel (Bolted) |
| MATERIAL IMPELLER RINGS: | Not Known |
| MATERIAL-CASING RINGS: | " " |
| RADIAL CLEARANCE: | " " |
| MATERIAL BALANCING RINGS: | " " |
| MATERIAL INTERSTAGE SEAL. | " " |
| RADIAL CLEARANCE: | " " |
| MATERIAL DIFFUSER: | " " |
| BEARING: | Pillow Block - Oil under pressure |
| THRUST BEARING: | Two rings in bearing |

| | |
|---|---|
| TYPE OF PACKING: | Mechanical |
| MATERIAL OF PACKING: | Carbon Rings |
| MATERIAL OF SLEEVE: | Bronze |
| CLEARANCE: | None |
| REMARKS: | Original bronze sleeve.<br>Carbon rings changed once. |

**MOTOR OR GENERATOR:**

| | |
|---|---|
| TYPE: | Horizontal Synchronous<br>Exciter beyond turbine |
| MANUFACTURER: | Ercole Marelli & Cia (Miland) |
| H. P.: | 50 mw |
| R. P. M.: | 500 |
| VOLTAGE: | 15,000 |
| STARTING: | By turbine |
| REMARKS: | - |

**TURBINE:**

| | |
|---|---|
| TYPE: | Horizontal - Francis |
| MFG.: | San Giorgia |
| HEAD: | 850' |
| R. P. M.: | 500 |
| H. P.: | 50 mw |

REMARKS: No. II unit down to replace cracked stainless turbine runner. Being replaced by cast steel, same as No. I unit.

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | Rotary |
| MANUFACTURER: | Tosi - San Giorgio |
| SIZE: | 90.5" |
| OPERATION: | Turned by oil pressure. Seal operated by water pressure. |

DISCHARGE:

| | |
|---|---|
| TYPE: | Spherical (Two in series) |
| MANUFACTURER: | Riva |
| SIZE: | 67" (1700 mm) |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | 7 Seconds |
| EMERGENCY: | - |

REMARKS: Two spherical valves in series, one operated by oil pressure and the second mechanically. Discharge valve opens automatically when pump pressure reaches static head - about 390 RPM.

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | One 14.75' ( 4.5 MTS) |
| LENGTH: | Vertically from station 820', then to gently sloping tunnel 3480' to Campotosto Lake.<br>Inlet Penstock (underground) 8.2' x 2200' with surge tank near station inlet. |

| | |
|---|---|
| MATERIAL: | - |
| TYPE OF UPPER GATE: | - |
| SURGE TANK: | 32.8' dia. surge tank at top of vertical shaft. |
| REMARKS: | Very small surges - 3% rise and 14% depression when cutting off 46,000 kw. |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Excellent - clear, clean, cold |
| Ph: | Unknown  Solids: Nil |
| HARDNESS: | Soft |
| REMARKS: | Water temperature 43°F - 42°F |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | Seasonal - 6-7 hrs. per night |
| STARTS/DAY: | Once per day (more or less) |

HOURS OF OPERATION:

| | | | |
|---|---|---|---|
| Generative | 44,726 | 24,623 | 4180 |
| Pumping | 24,543 | 12,820 | 928 |

| | |
|---|---|
| UNPLANNED OUTAGES: | None |
| CAUSE: | - |
| INSPECTION SCHEDULE: | Twice in 11 years |
| TIME REQUIRED: | Few hours |
| OVERHAUL SCHEDULE: | Never overhauled |
| TIME REQUIRED: | - - |
| IMPELLER CAVITATION: | None |

SEAL RING WEAR: None apparent

NOISE LEVEL-START: A= 100-3; B= 100+3; C= 100+3

NOISE LEVEL-RUN: A= 100-1; B= 100+3; C= 100+4

VIBRATION: None

REMARKS: Noise appears to come from coupling. Slight cracking sound at inlet.

Pumps have been running 11 to 13 years with practically no inspection, nor repairs.

Original impellers cut down when frequency changed.

Operating force consists of one Foreman, two aides, and one switch control man.

Unit No. III consists of a 65,000 kva reversible pump set, vertical, San Giorgia generator-motor and Allis Chalmers pump.

Turbine started with reduced voltage about 200 times and operated as a pump 928 hours, but due to overheating of amortisseur windings, pump operation discontinued. They are now arranging connections to start this unit synchronized with a turbo-generator set at stand-still.

## GENERAL REMARKS

On September 22 and 23, 1964, Mr. Cole and Mr. Peter Lutz from Motor-Columbus visited the two above plants, both owned by the E. N. E. L. (Ente Nazionale Energia Electrica) the state owned electric power system, and located in Central Italy. Both stations are used for supplying energy to the Italian network.

These two plants, more or less identical in arrangement, contain two horizontal units; each consisting of exciter, Francis turbine, generator-motor and pump. Provvidenza also contains a vertical unit consisting of a San Giorgio generator-motor and an Allis-Chalmers combination turbine and pump.

Provvidenza horizontal units operate as a pump daily, usually from about midnight until morning and the rest of the time as a generator with the pump disconnected. The AC unit operates now as a turbine unit only.

Cotilia operates as a pump only in the spring when there is an excess of hydraulic energy in Northern Italy, therefore, this unit could not be observed operating as a pump.

Although these units have been operating for many years, one pump almost 25,000 hours, relatively little trouble has been experienced with the pumping units. The Cotilia units were dismantled in 1949 when the impeller was cut to accommodate the change in frequency from 45 to 50 cycles and again in 1953 and 1954. The wearing rings were changed twice, once due more to eccentricity than wear. Original casing rings were of cast iron, later ones of stainless steel. Slight evidence of cavitation was corrected in 1954 by welding.

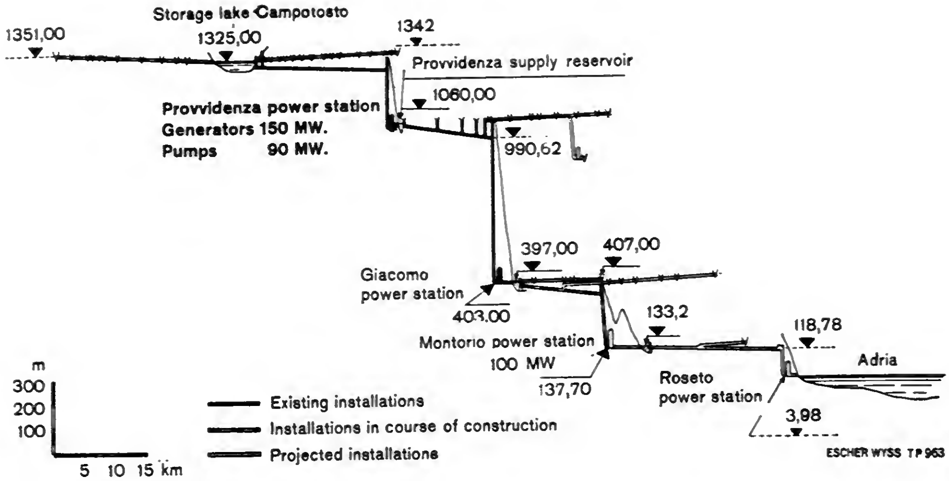
The Provvidenza units have never been dismantled. They were inspected through hand holes twice in 11- 13 years. Ring wear unknown but apparently not enough to affect capacity or H.P. No evidence of cavitation (according to operator's statement, although there is an audible cracking sound of the water entering the impeller).

All units started by the turbine. Pumps never operate at cut-off head, as the valve opens as soon as the static head is reached.

The Allis-Chalmers/San Giorgio unit has some vibration, but probably nothing serious. This unit is arranged for line starting with two steps of reduced voltage. However, the amortisseur windings heated considerably and, eventually, the interconnections expanded and touched stator coils. Use as a pump was discontinued. Arrangements are now being made to start this unit by a turbine unit more or less like the system used at Grand Coulee. The District Manager at Provvidenza recommended that this system be employed in the Tehachapi project, even though this would require a turbo-generator unit per station of about one-half the full load capacity of the pump motors.

This plant, completely un-automated, Operators await phone call, then perform all operations by hand in certain sequence -- to switch, to pumping cycle. Turbine valve closed and turbo-generator stops in 23 minutes. Coupling connected by air, oil pump started, suction valve opened -- turbine started again - synchronized, turbine dewatered. Pumping cycle, pump and motor stop in six minutes.

Practically no repairs are carried out at either station. One set of bearings is carried at Provvidenza but never used. However, both stations are relatively close to Terni where the heavy parts of one of the Provvidenza pumps were made, and this shop is capable of making any repair part rapidly.



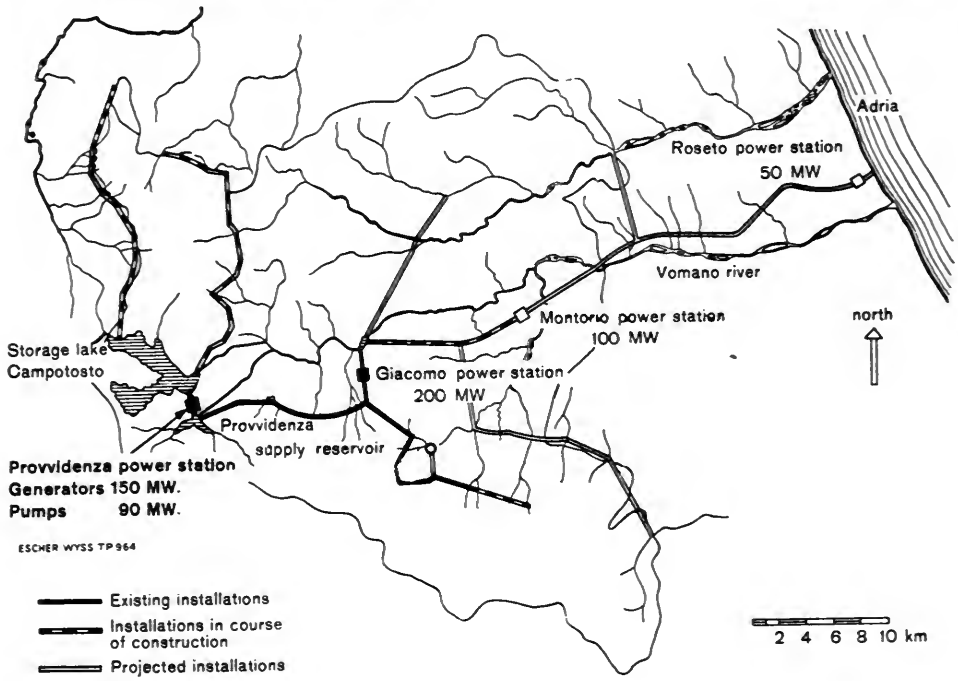




Fig. 28.1 (Left) Profile of System and Geographic Location

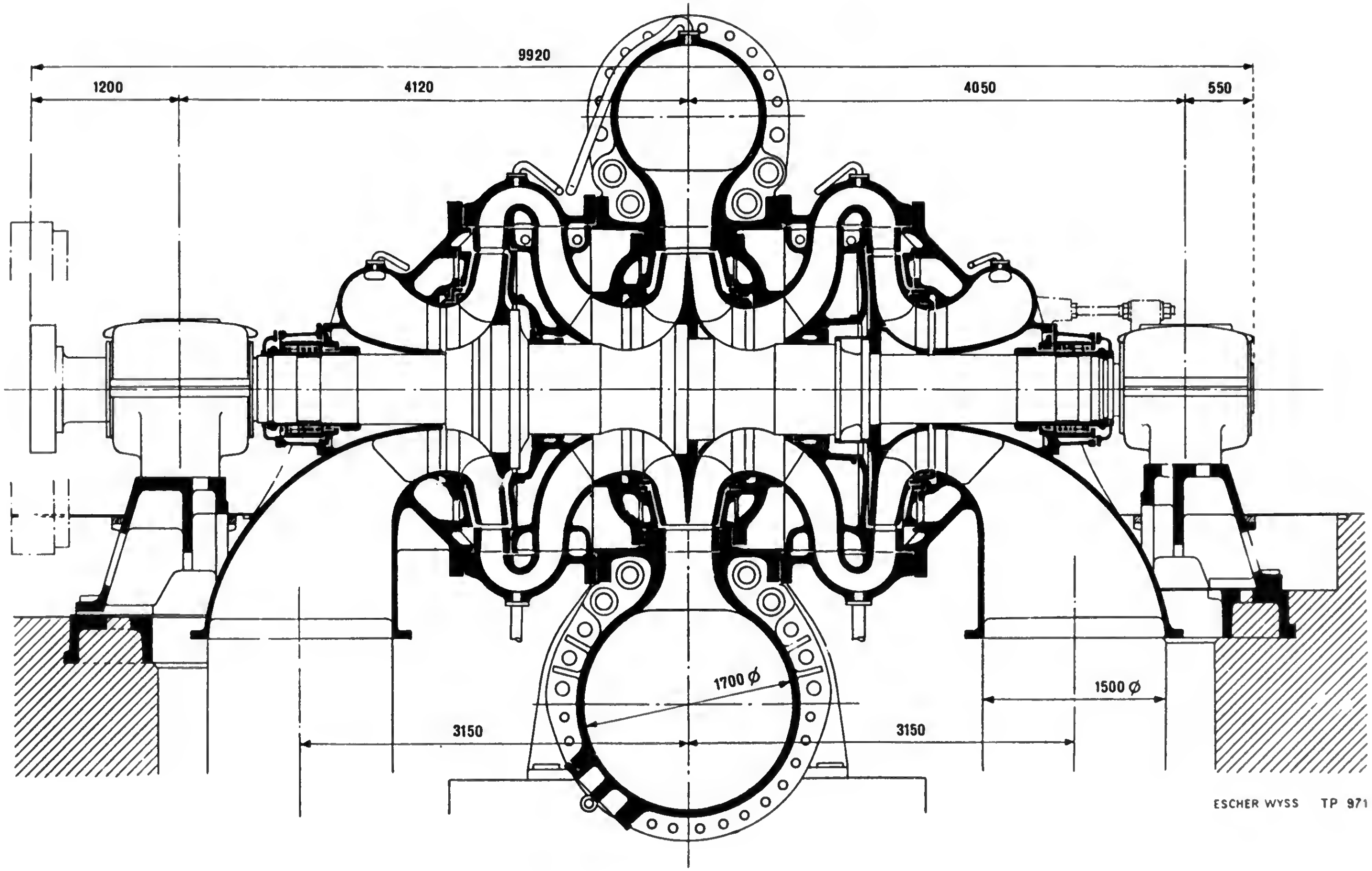



Fig. 28. 2 (Below) Suction through Escher Wyss Pumps

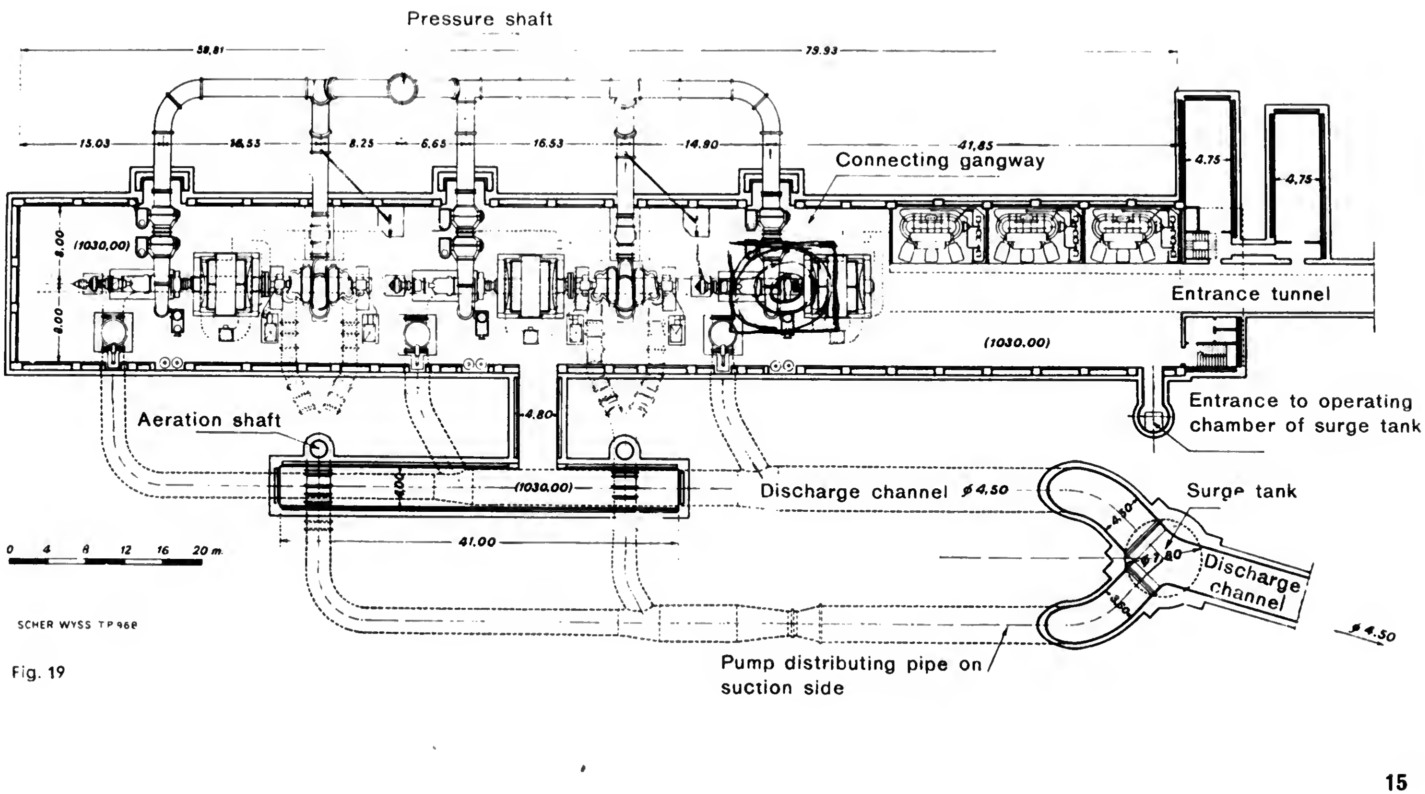



Fig. 28.3 - Plan of Station

Note: Unit at right replaced by vertical unit.

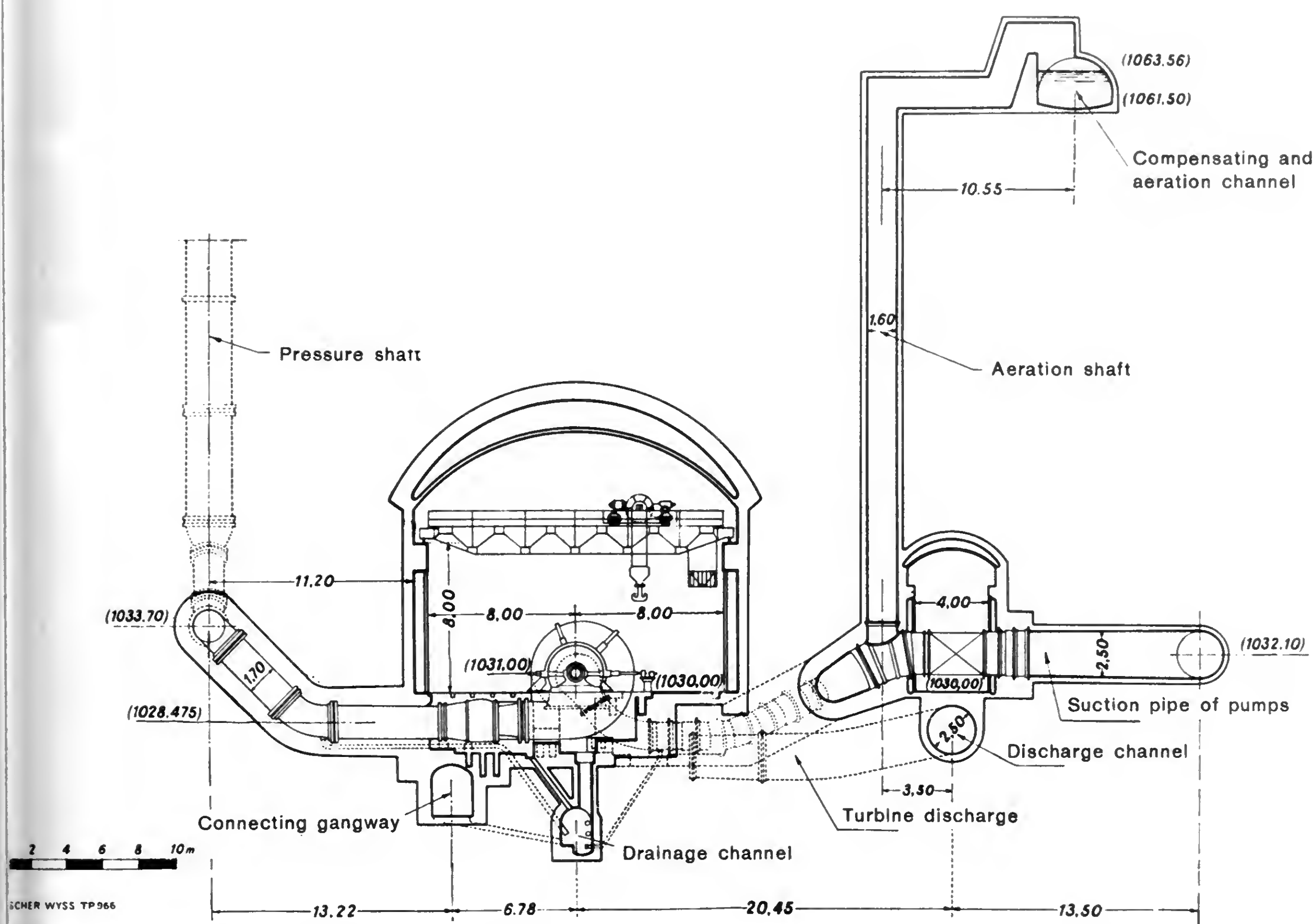



Fig. 28.4 - Section of Station

Fig. 28.5

View from Control Room

Fig. 28.6

AC - San Giorgia Unit

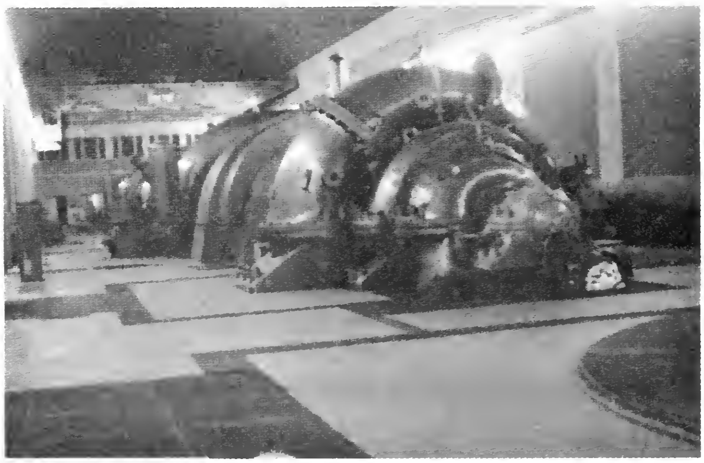


Fig. 28.7

View from Pump end

Fig. 28.8

Coupling End of Pump

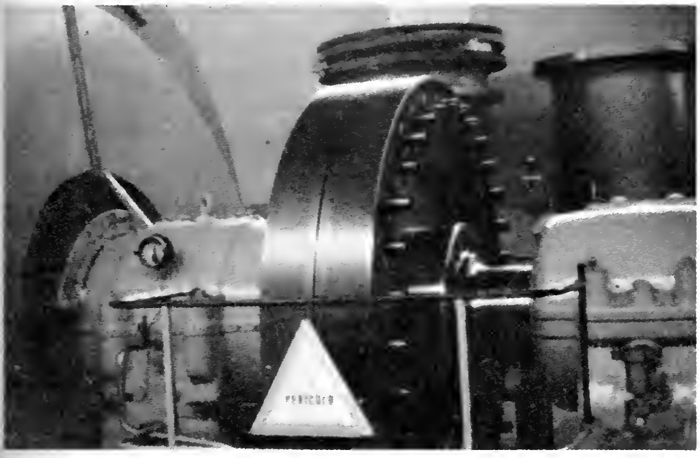


Fig. 28.9

Coupling

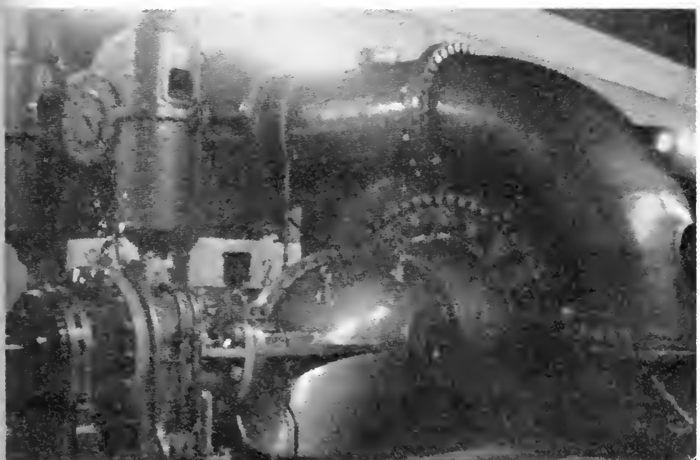


Fig. 28.10

Turbine

## Vibration Records

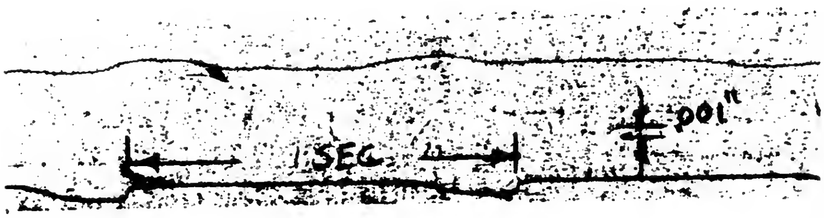
Ente Nazionale Energia Electtrica (ENEL), Firenze, Italy

Plant : Provvidenza (underground power house)

Units : two (units 1 and 2), 2-stage, double flow, horizontal pumps; 67,000 HP, 500 cfs, 870 ft, 500 RPM.
one (unit #3), reversible pump turbine, vertical; 87,000 HP, 600 cfs, 834 ft, 375 RPM.

Records taken: September 23, 1964

Pump #1




1. Start

2.

3.

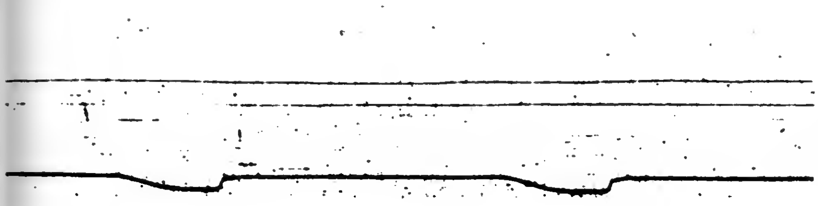
| Frequency c.p.m. | Average Amplitude inches |
| --- | --- |
| ---- | .0003 |
| ---- | less than .0002 |
| ---- | less than .0002 |

Figure 28.11

## Vibration Records (cont.)

Ente Nazionale Energia Electtrica (ENEL), Firenze, Italy

**Plant** : Provvidenza (underground power house)



4.

5.

6.

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| ---- | less than .0002 |
| ---- | less than .0002 |
| ---- | less than .0002 |

Figure 28.12

PLANT NAME: AROLLA

REPORT NO.: 29

| | |
|---|---|
| LOCATION-ALTITUDE: | Val d'Herence - Switzerland - 6600' |
| OWNER: | Grande Dixence, SA. |
| ADDRESS: | Lausanne, Switzerland |
| TYPE OF PLANT: | Surface |
| SERVICE | Pumping only |
| TYPE OF WATER: | Glacial water - milky |
| UNITS INSTALLED: | Three 2-stage, double-suction horizontal pumps. |
| HORSEPOWER: | 3 x 19,275 (1500 RPM) |
| CFS: | 3 x (146 - 150) |
| STATIC HEAD: | 1000' ± |
| PLANT STARTED: | I & II - May 1963 - III - Oct. 1963 |
| VISITED BY: | Cole - Hartmann |
| DATE: | October 1, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Henri Meier - Resident Engineer |
| REMARKS: | This plant takes all the water delivered by the Ferpecle Plant, plus an additional 30%, and delivers it to the main collecting tunnel of the Grande Dixence Storage Lake. |

## PUMPS:

| | |
|---|---|
| TYPE: | Horizontal - 2-stage, double-suction |
| MANUFACTURER: | Sulzer |
| SIZE DISCHARGE: | IA & IB - 19.7"; II & III - 29.5" |
| SIZE SUCTION: | 2 x 23.4" |
| RPM: | 1500 |
| CFS: | 146 - 151 |
| HEAD: | 1030 - 2640 |
| H.P. REQUIRED: | 19,000 - 19,100 |
| N s.: | 2550 - 2640 |
| INSTALLED: | 1963 |
| HRS. OF OPERATION | IA - 2785; IB - 1216; II - 2127; III - 1127 |
| MIN. SUBMERGENCE: | 213' |
| NORMAL SUBMERGENCE: | 236' |
| MAX. SUBMERGENCE: | 250' |
| REMARKS: | Unit No. I is a duplicate of II & III but split in two with one-half of the unit on each end of the motor. Each half has a capacity of 75 cfs. |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | No Model |
| MODEL ACTUAL: | " " |
| PROTOTYPE-GUARANTEED: | I- 89; II & III- 89. 5 |
| PROTOTYPE-ACTUAL: | 87 88 |
| METHOD OF TEST: | Thermodynamic method (in June 1964 wear had progressed). |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | I- 19. 7" - II & III- 27. 5" |
| DIAMETER IMPELLER: | 1st stage - 31"; 2nd stage - 33. 4" |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | - |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | Stainless - 14 Cr. 1 Ni. |
| MATERIAL IMPELLER RINGS: | Stainless Steel |
| MATERIAL-CASING RINGS: | Stainless (Grooved) |
| RADIAL CLEARANCE: | - |
| MATERIAL BALANCING RINGS: | None |
| MATERIAL INTERSTAGE SEAL: | - |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | Cast Steel |
| BEARING: | 7. 1" x 7. 9" Steel - Babbitt |
| THRUST BEARING: | Disc. 17" O.D. (No. 1 only) |

| | |
|---|---|
| TYPE OF PACKING: | Labyrinth |
| MATERIAL OF PACKING: | - |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | No drawings at plant to check construction details. |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Horizontal-synchronous, solid pole construction. |
| MANUFACTURER: | Sécheron (Geneve) |
| H. P. | 22,000 CV (22,308 HP) |
| RPM: | 1500 |
| VOLTAGE: | 7000 |
| STARTING: | Reduced voltage (see remarks) |
| REMARKS: | Motor has exciter incorporated in the rotor. |

TURBINE:

| | |
|---|---|
| TYPE: | None |
| MFG: | - |
| HEAD: | - |
| RPM: | - |
| H. P. : | - |
| REMARKS: | - |

VALUES:

INTAKE:

| | |
|---|---|
| TYPE: | None installed (Must drain suction line to work on pump) |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | - |

DISCHARGE:

| | |
|---|---|
| TYPE: | Spherical |
| MANUFACTURER: | Charmilles |
| SIZE: | I - 19.7"; II & III - 27.5" |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |

REMARKS: Bypass (2.25 - 42.5 CFS) controlled automatically. BP valve chattered excessively. Energy absorber installed. BP failed to open once - pump overheated - shaft warped - interseal scored.

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | One (5.4' - 6.9') |
| LENGTH: | 310 ± - 80% slope. |

| | |
|---|---|
| MATERIAL: | Steel lined until 50 MTS from top, then concrete lining only. |
| TYPE OF UPPER GATE: | - |
| SURGE TANK: | - |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Glacial melt - milky - contains fine particles of granite, gneiss, quartz, etc. |
| Ph: - | |
| HARDNESS: | - |
| REMARKS: | 70% of water comes from Ferpecle. |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | Full load during melting season - Rarely in Winter. |
| STARTS/DAY: | Varies with Season |
| HOURS OF OPERATION: | IA - 2788; II - 2127; III - 1627; IB - 1216 |
| UNPLANNED OUTAGES: | 7 ± |
| CAUSE: | Pump 3 - Electrical 3 - Valve 1 |
| INSPECTION SCHEDULE: | None |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | None Established |
| TIME REQUIRED: | - |
| IMPELLER CAVITATION: | None |

SEAL RING WEAR: Yes

NOISE LEVEL-START: A- 197; B- 99; C- 99

NOISE LEVEL-RUN: A- 92; B- 96; C- 96

VIBRATION: None

REMARKS: The Arolla Plant is beautifully constructed, well lighted, and very roomy. However, for some unknown reason, there are no valves in the suction lines, making it necessary to drain the inlet line and shut down the whole station to work on the pump; and 2) the pumps are of the non-split case design, so that for dis-assembling all parts have to be stripped off the outboard bearing end of the shaft. No space was provided for removing the bearing pedistal, and stripping the pump in place, so that to inspect the interior of the pump, the entire pump must be lifted out of its pit and set to one side.

## GENERAL REMARKS

Arolla has three units. All the motors are the same, however, the pumps of units No. 2 and 3 are two-stage, double flow, while the pumps of Unit No. 1 are 2-stage, single flow and arranged on both sides of the motor. Pump 1a is rigidly coupled with the motor, while between motor and pump No. 1b there is a gear coupling. This arrangement allows to operate the plant with 1/2, 1, 1-1/2, 2 . . . . times the unit capacity, which is necessary to adjust it to the water inflow. The balancing reservoir of Arolla had to be made underground and is, therefore, rather small.

The pumps are started filled with water. The motors are of Sécheron, Geneva/Switzerland, manufacture with massive poles. They start with 3000 V, after 20 s the voltage is increased by 500 V and then in six other steps which follow in time increments of 2-1/2 s each, the voltage is increased by 500 V in each step to reach the rated voltage of 7000 V. Each unit has its own transofrmer and starting is made through taps on the transformer. Excitation is applied when the final voltage step is reached. The transformers are also of Sécheron manufacture.

The pumps have all impellers, diffusors and return pieces from the first to the second stage and wear rings of 13% Cr steel cast. We could not get data on the clearance as they had not all drawings available. The stuffing boxes are of the labyrinth type, 13% Cr, shaft sleeve and aluminum bronze bushing. The stationary wear rings and the stuffing boxes bushings have grooves like the Peccia pumps. The pumps run relatively smooth noise level was measured around 95 db.

Due to the glacial milk they are pumping, they have very extreme wear on the pumps (as also Stafel and Ferpecle). After 1068 operation hours they have changed the rings and repaired the impellers on unit 1a. We saw photographs of the impellers and wear rings. They show the very typical wave shaped surface which is caused by sand erosion. It should be clear that the conditions at the Grand Dixence pumping stations are really exceptional in this respect. Not only that they pump the water directly from the glaciers, the plants are also situated in the part of the country with granite, gneiss, quartz, etc. formations which produce a very hard and abrasive sand. They have sand traps installed and the water goes also through reservoirs before it goes into the pumps, but these reservoirs are much too small to settle out this fine, yet very abrasive material. The wear experience in these stations is exceptional in any way and should not be transmitted as a general experience to other cases. The following outages were reported for the pumps:

Due to a failure of the warm water valve (this is a relief valve which allows a small flow through the pump during starting to avoid heating up of the pump when operating against closed valve) the pump got so hot within five minutes that the stuffing box touched. As a result, the shaft sleeve had to be re-finished and the bronze bushing had to be replaced. Both parts did, however, not weld together. During commissioning of one pump, galling of the thrust bearing occurred as a result of unsufficient oil flow. The segments had to be replaced. Due to wear on the balancing labyrinth, the axial thrust increased to a non-permissible value, hereby damaging the thrust bearing. The bearing got hot and the segments had to be re-finished.

Two outages were caused by the motor:

The connecting cooper bands of the field winding from pole to pole were designed too stiff. They could not follow the movements caused by temperature and centrifugal stresses and, therefore, broke. The bronze rings shrunk on the massive poles to form the squirrel cage for starting had unsufficient contact. The very high current during starting caused charing at the contact surfaces. The bronze rings were replaced by copper bands.

One outage was caused by the transformer:

A piece in the cable terminal got loose, fell down and caused a short circuit and explosion of the cable terminal.

There were also modifications necessary on the field breaker.

No difficulties were reported here with relays. They have also 48 V DC Siemens relays. Each relay has its individual plastic cover. We had also the impression that the whole station Arolla is in a more finished state than Ferpecle and especially the relay room was much cleaner and showed less dust than in Ferpecle.

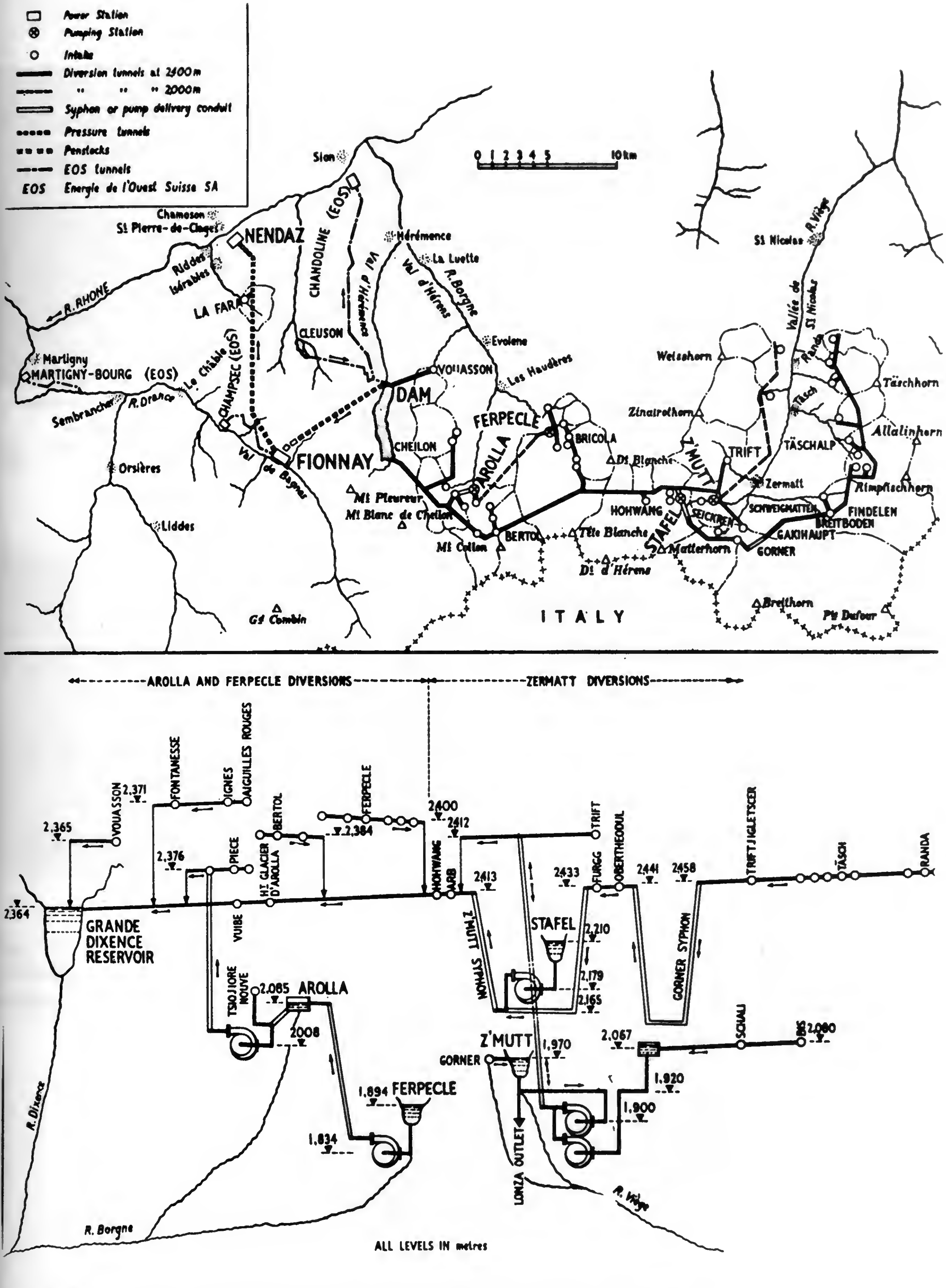



Fig. 29-1 - Schematic Plan of Grande Dixence System

Fig. 29.2

Station Facade - Arolla Peak in the distance

Fig. 29.3

General view of Interior

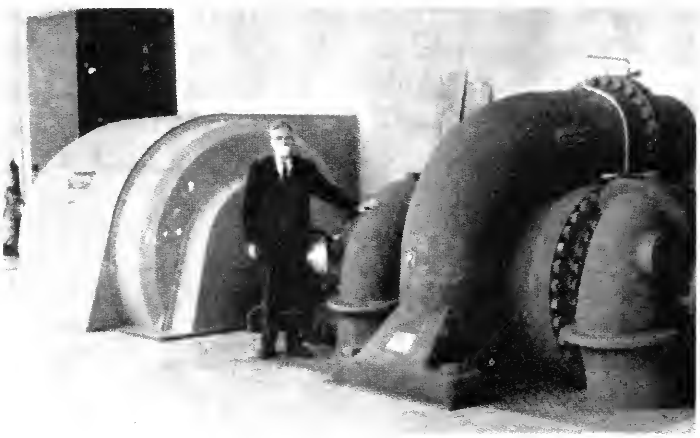


Fig. 29.4

View of Pump No. II

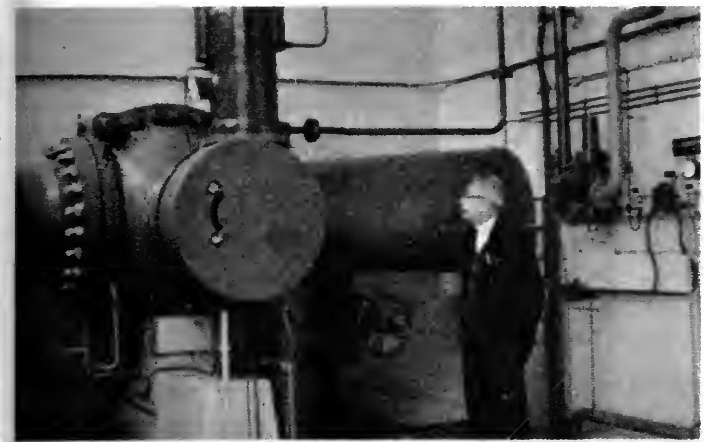


Fig. 29.5 - Discharge Valve

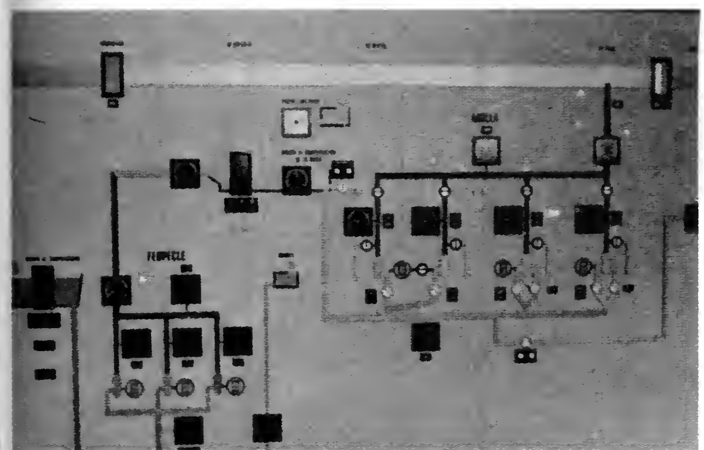


Fig. 29.6 - Control Board, including Ferpecle Remote-control

Fig. 29.7 - Impellers Removed from No. IA

## Vibration Records

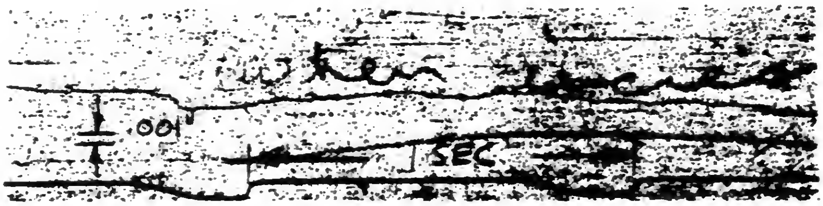
Grand Dixence S. A., Lausanne, Switzerland

Plant : Arolla (surface power house)

Units : two (units 1A and 1B), 2-stage, single flow, horizontal pumps (arranged on both sides of a common motor); 19,000 HP and 148 cfs (both pumps engaged), 9500 HP and 74 cfs (one pump engaged), 1017 ft, 1500 RPM.
two (units 2 and 3), 2-stage, double flow, horizontal pumps; 19,000 HP, 148 cfs, 1017 ft, 1500 RPM.

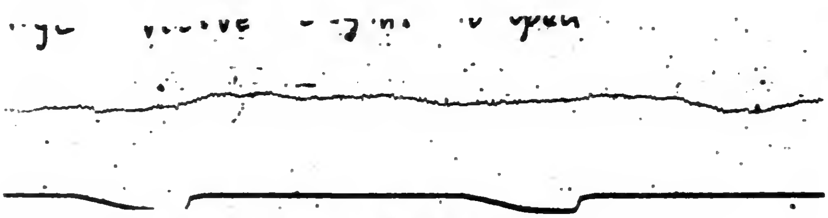
Records taken: October 1, 1964

Unit #2, Volute

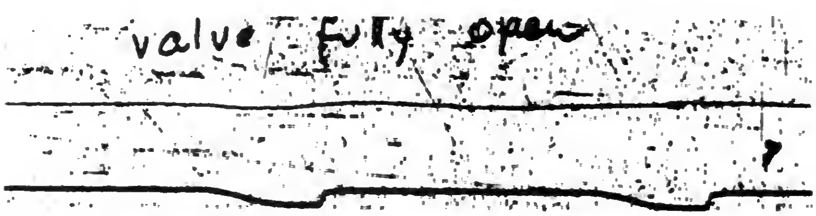



1. Starting from 0 rpm

2. Full speed



3. Discharge valve begins to open




4. Valve fully open

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 6300 | .0003 |
| 7200 | .0006 |
| 6600 | .0004 |
| ---- | less than .0002 |

Figure 29-8

PLANT NAME: FERPECLE

REPORT NO.: 30

| | |
|---|---|
| LOCATION-ALTITUDE: | Val d'Herence, Wallis/Switzerland - 6000' |
| OWNER: | Grande Dixence, SA. |
| ADDRESS: | Lausanne, Switzerland |
| TYPE OF PLANT: | Underground |
| SERVICE | Pumping onlv |
| TYPE OF WATER: | Glacial melt - not good |
| UNITS INSTALLED: | Three single-stage, single-suction horizontal pumps |
| HORSEPOWER: | 3 x 9500 HP (1500 RPM) |
| CFS: | 3 x 98 |
| STATIC HEAD: | 630' |
| PLANT STARTED: | May 1964 |
| VISITED BY: | Cole - Hartmann |
| DATE: | October 1, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Henri Meier, Resident Engineer |
| REMARKS: | Plant located in a steep valley, 1 KM downstream from toe of glacier. Delivers water to surge tank (inside the mountain), which supplies Arolla. Operation controlled from Arolla. |

## PUMPS:

| | |
|---|---|
| TYPE: | Single-Suction, Single-Stage Horizontal |
| MANUFACTURER: | Escher-Wyss |
| SIZE DISCHARGE: | 24.6" |
| SIZE SUCTION: | 31.4" |
| RPM: | 1500 |
| CFS: | 99 |
| HEAD: | 700 |
| H.P. REQUIRED: | 8700 |
| N s.: | 2340 |
| INSTALLED: | May 1964 |
| HRS. OF OPERATION | I- 1922; II- 1401; III- 1930; (until 10/1/64) |
| MIN. SUBMERGENCE: | 125 |
| NORMAL SUBMERGENCE: | - |
| MAX. SUBMERGENCE: | 197 |

REMARKS: Pumps operated daily to empty forebay. Practically continuously during Summer. Pumps very noisy, or at least appear so due to acoustics. Pumps and suction elbow painted with thick coat of plastic material called ANTIDROEHN, but this has little apparent affect, except to reduce condensation. Maximum and minimum submergence reached daily.

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | No model |
| MODEL ACTUAL: | " " |
| PROTOTYPE-GUARANTEED: | 90. 4 |
| PROTOTYPE-ACTUAL: | Results of test unknown |
| METHOD OF TEST: | Thermodynamic - Sept. 1964 |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 24. 6" (625 mm) |
| DIAMETER IMPELLER: | 35. 3" (900 mm) |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 11. 8" (in Brg.) |
| MATERIAL CASING: | Steel |
| MATERIAL IMPELLER: | 13% Cr. - 1% Ni |
| MATERIAL IMPELLER RINGS: | Stainless |
| MATERIAL-CASING RINGS: | Bronze |
| RADIAL CLEARANCE: | 0. 4 to 0. 48 mm |
| MATERIAL BALANCING RINGS: | - |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | 13% Cr. - 1% ni |
| BEARING: | 4. 7" x 11. 8" (Oil pressure) |
| THRUST BEARING: | 15. 7" Disc. (Media dia.) |

| | |
|---|---|
| TYPE OF PACKING: | - |
| MATERIAL OF PACKING: | - |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | Single bearing - overhung impeller. 200 + GPM leakage from stuffing box when pump not running. |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Horizontal - Synchronous |
| MANUFACTURER: | Brown Boveri |
| H. P. | 9550 (7100 kW) |
| RPM: | 1500 |
| VOLTAGE: | 5000 |
| STARTING: | Direct - full voltage - closed valve. Comes up to speed in 3.5 seconds. |
| REMARKS: | Solid pole motors without amortissuer windings. |

TURBINE:

| | |
|---|---|
| TYPE: | None |
| MFG: | - |
| HEAD: | - |
| RPM: | - |
| H. P.: | - |
| REMARKS: | - |

## VALVES:

### INTAKE:

| | |
|---|---|
| TYPE: | Butterfly |
| MANUFACTURER: | Escher-Wyss |
| SIZE: | 31.5" (800 mm) |
| OPERATION: | Manual - with counter-weight |

### DISCHARGE:

| | |
|---|---|
| TYPE: | Spherical |
| MANUFACTURER: | Escher-Wyss |
| SIZE: | 24.5" (625 mm) |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | Counter-weight - Piston controlled |
| TIME OF CLOSING: | |
| NORMAL: | 50 seconds |
| EMERGENCY: | 80% in 1.5 seconds - 100% in 5 seconds. |
| REMARKS: | Emergency seal on downstream side. Seal in rotating part allows 7 CFS to bypass. |

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | One - 5.25' dia in Rock. |
| LENGTH: | 1050 ± (80% slope) |

| | |
|---|---|
| MATERIAL: | Steel lined until 164' from top. |
| TYPE OF UPPER GATE: | None |
| SURGE TANK: | None |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Glacial melt - Milky - errosive, abrasive. |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | Contains particles of granite, gneiss, quartz, etc. Settling basin and sand traps used, but are inadequate to catch fine particles. |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | Summer - practically continuously<br>Winter- Short periods daily. |
| STARTS/DAY: | Three (maximum) |
| HOURS OF OPERATION: | I- 1722; II- 1410; III- 1730 |
| UNPLANNED OUTAGES: | None |
| CAUSE: | - |
| INSPECTION SCHEDULE: | Once per year planned. |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | Too early to determine. |
| TIME REQUIRED: | - |
| IMPELLER CAVITATION: | None |

| | |
|---|---|
| SEAL RING WEAR: | Yes - 1 mm in five months. |
| NOISE LEVEL-START: | C- 103 |
| NOISE LEVEL-RUN: | A- 103; B- 102; C- 101 |
| VIBRATION: | Some |

REMARKS: Except for excessive noise, pumps operating without difficulty. Noise level somewhat higher in valve room below pump, than near unit.

Some difficulty with relays sticking on remote control, probably due to start.

A rather superficial examination of pump by removing suction elbow made previous to tests a month ago, after five months of operation. Ring wear on bronze ring had increased approximately 1 mm in five months of operation. No apparent wear on stainless steel rings. No perceptible erosion of impeller. Seal ring wear evident from increased flow of water when shut down.

Oil leakage from motor bearing, probably due to cold ambient and too small drain pipe. Now being investigated by motor manufacturer.

## GENERAL REMARKS

Ferpecle is operated since May 1964 and, therefore, the experiences are restricted. The pumps have so far not been opened, but units No. 1 and No. 3, having now around 1700 operating hours, will be opened for inspection and repairs during October 1964. If the inspection of pumps No. 1 and No. 3 should prove that there is considerable wear, they will also open No. 2, which has 1400 operating hours so far.

One pump has been tested, using the thermo-dynamical method. These tests were made in September 1964 by Escher Wyss. The results are not yet definite but preliminary results show an efficiency slightly below guarantee, probably due to wear. An inspection foregoing the tests had shown that the wear ring clearance had increased by approximately 1 mm during the short operation of only 5 months. Mr. Meier said, "the wear was mainly on the bronze ring, while the stainless steel ring did not show any significant wear". The ring on the impeller is of stainless steel, 13% Cr, while the stationary wear ring is of bronze. This control, foregoing the efficiency tests, was made by dismantling the suction elbow. The impeller itself did not show much erosion. The balancing rings have not been inspected, but it is assumed that they are in a similar condition as the wear rings on the suction side of the impeller. The shaft sealing consists of a stainless steel sleeve on the shaft and a bronze bushing, clearance 0.40 - 0.479 mm radial according to drawings. Motors are of BBC manufacture, 7100 kW, 5000 V, with massive poles (not laminated), no amortisseur winding. Starting is direct on line with the pump filled with water. The unit goes up to the rated speed of 1500 rpm with 3.5 s.

There were no outages or other operating troubles with these units, except considerable frequent failures of instruments and especially of the relays of the automatic control. They use 48V direct current in the control system and have considerable troubles with dust in the relay boxes. It is assumed that this will become better once the station is really finished and clean. No difficulties have been experienced with the motor, only oil vapor from the outside bearing contaminated the exciter and, under certain circumstances, they have oil overflow on this bearing because the return pipe to the oil tank is too small. The pumps are operated throughout the year in principle, however, the main operating time is in the summer. During the snow melting period, they run the three units 24 hours a day, while in winter the water inflow decreases to an extent that they use only one pump for a few hours per day.

The pumps are rather noisy, of a very distinct humming tone. It seems that most of the noise comes from the suction elbow which is of welded steel plate construction, probably even in resonance. It can be assumed that the noise would be much less if this part would be of cast steel, as all the rest of the pump is. The pumps are painted with a thick layer of plastic material called "ANTIDROEHN". The same material was also applied on the pumps and turbines of Peccia and Tierfehd. As also in these cases, the operating people say that the effect of this paint is negligible with respoect to noise suppression, but it reduces the water condensation.

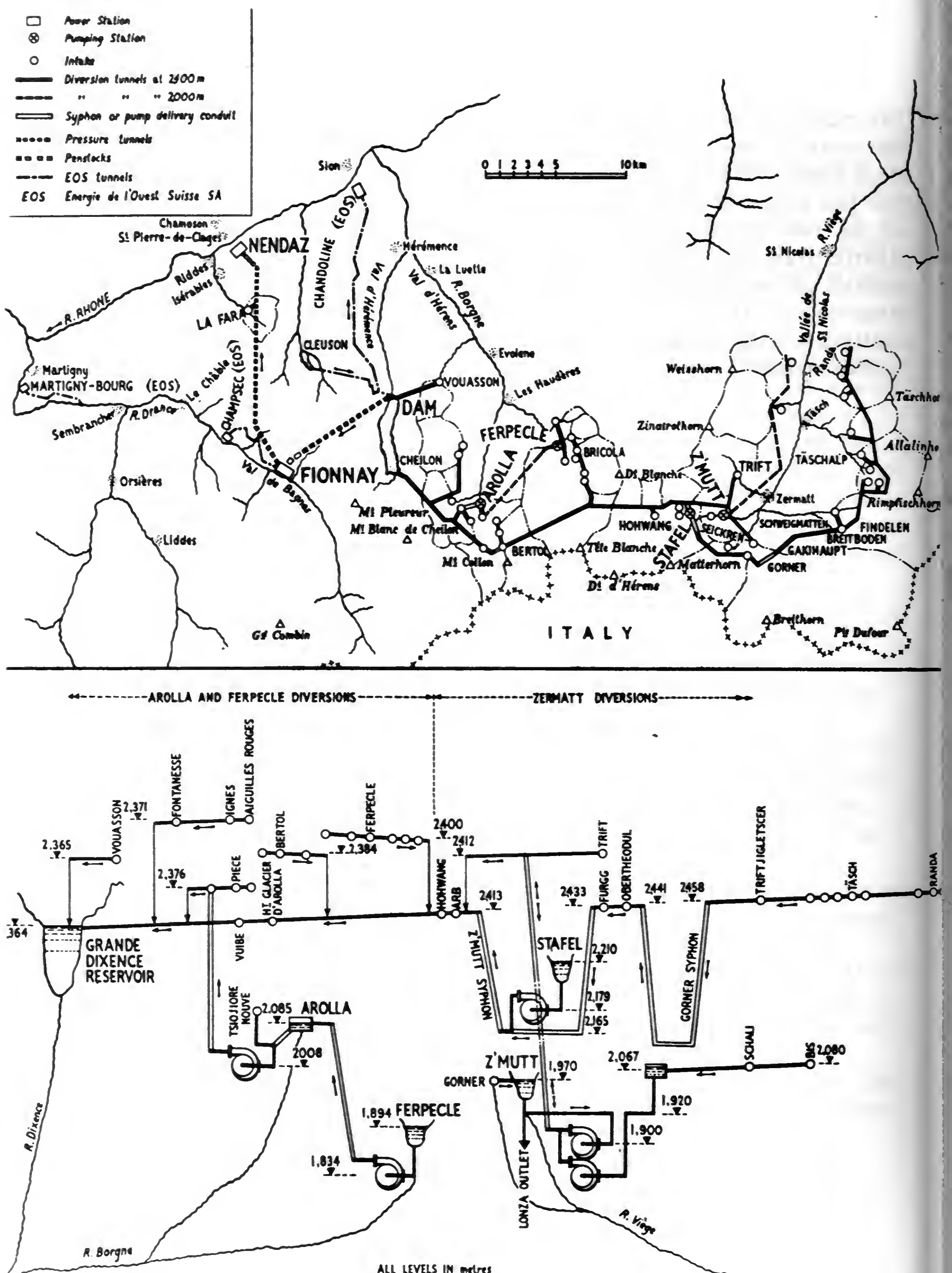



Fig. 30. 1 - Schematic Plan of Grande Dixence System

Fig. 30. 2 - View of Valley
Les Haudres in foreground.
Dent-Blanche in the distance.

Fig. 30. 3 Intake Reservoir with
Spillway - Glacier in background.

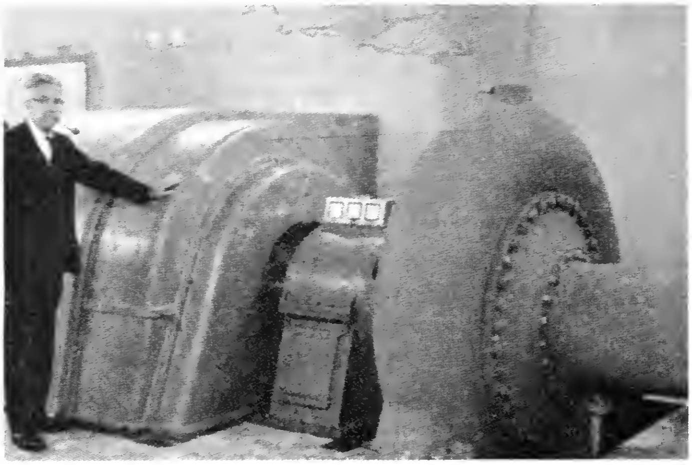


Fig. 30.4

View of Pump and Motor

Fig. 30.5 - Discharge Valve

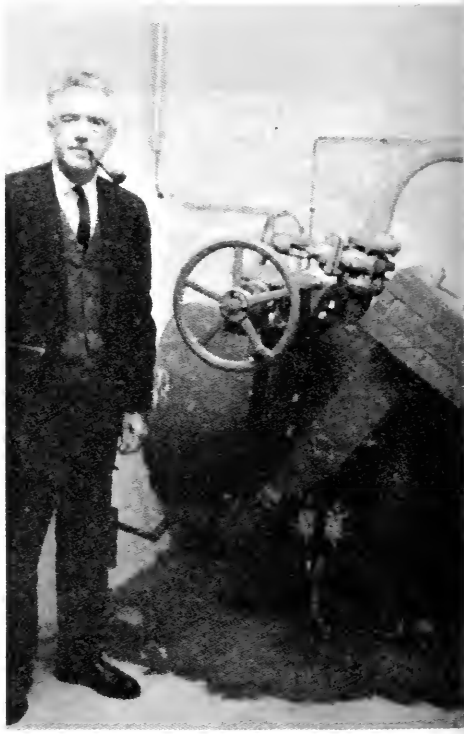


Fig. 30.6 - Butterfly Suction Valve

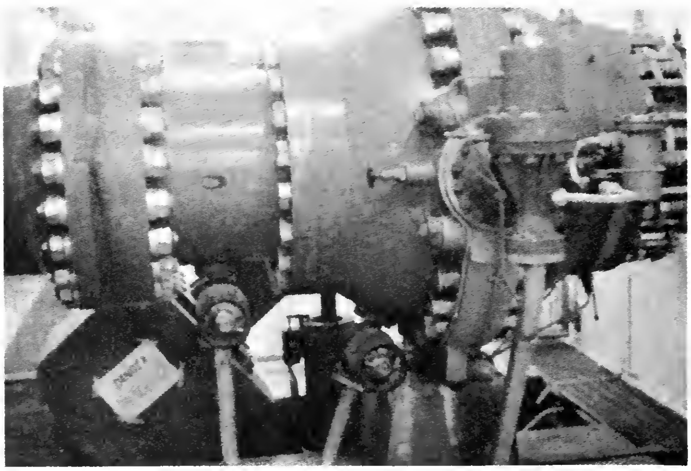


Fig. 30.7 - Discharge Valve

## Vibration Records

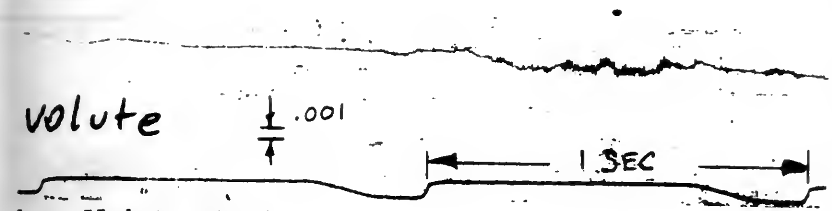
Grand Dixence S. A., Lausanne, Switzerland

Plant : Ferpecle (underground power house)

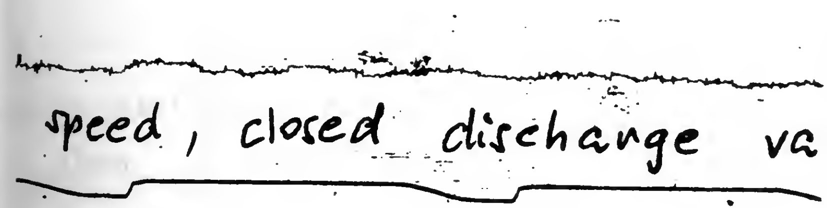
Units : three, 1-stage, single flow, horizontal pumps; 9500 HP, 98 cfs, 700 ft, 1500 RPM.

Records taken: October 1, 1964

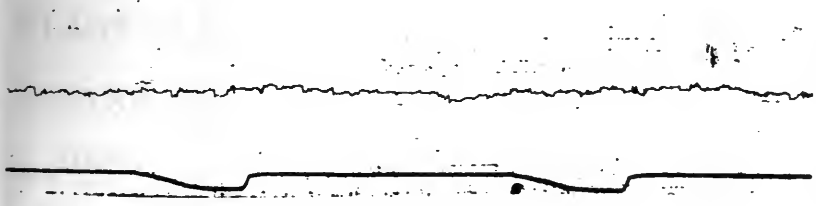
Unit II



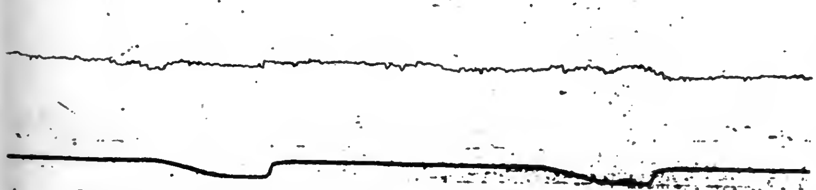

1. Volute start




2. Full speed



3. Bearing



4. Suction cover, valves opens

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| from ---- to 7200 | less than .0002 to .0005 |
| 7200 | .0006 |
| 12,000 | .0003 |
| 5100 | .0004 |

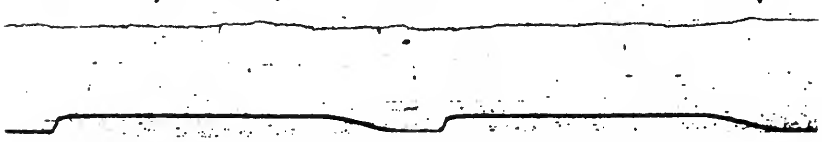
Figure 30-8

Vibration Records (cont.)

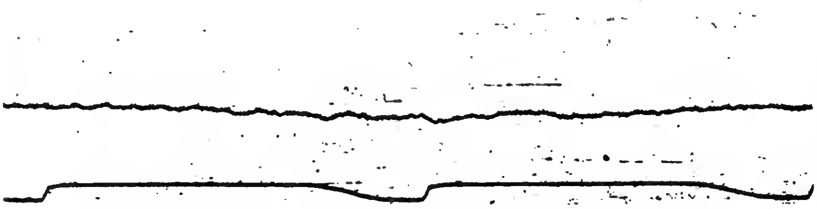
Grand Dixence S. A., Lausanne, Switzerland

Plant : Ferpecle (underground power house)

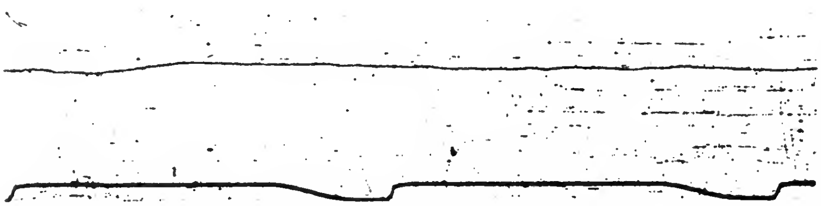
: fully open, normal pumpi



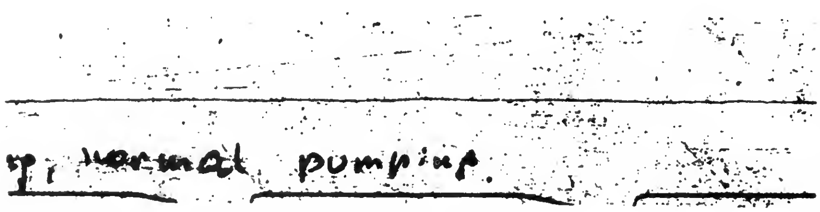
5. Suction cover, normal pumping



6. Suction Elbow, normal pumping



7. Volute, normal pumping




8. Bearing, normal pumping

| Record | Frequency c.p.m. | Average Amplitude inches |
|---|---|---|
| 5. | ---- | .0002 |
| 6. | 22, 800 | .0003 |
| 7. | ---- | .0002 |
| 8. | ---- | .0002 |

Figure 30-9

PLANT NAME: GEESTHACHT

REPORT NO.: 31

| | |
|---|---|
| LOCATION-ALTITUDE: | 22 Mi. West of Hamburg, Germany on the River Elbe - 8.3' |
| OWNER: | Hamburg Elektricitats Werke A. G. |
| ADDRESS: | Hamburg, Germany |
| TYPE OF PLANT: | Surface - Power Generation - Pump Storage |
| SERVICE | Utility Power for Hamburg and vicinity |
| TYPE OF WATER: | River Water - Poluted but free of sand |
| UNITS INSTALLED: | Three (3) Horizontal Turbine, Generator Pump units - Single-Stage - Double Suction |
| HORSEPOWER: | 3 x 41,500 HP - 214 RPM |
| CFS: | 3 x 1161 |
| STATIC HEAD: | 250' |
| PLANT STARTED: | Feb., June, and Oct. 1958 |
| VISITED BY: | Cole - Hartmann |
| DATE: | Oct. 5, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | K. Hoffmann, Electrical Plant Sup., Deputy Plant Chief |

REMARKS: A very low head pump storage plant, requiring rather large sized units. A large, spacious and well designed plant - 40' x 356' covered by removable hatch covers.

Machines can be put in service as generators in 100 seconds.

PUMPS:

| | |
|---|---|
| TYPE: | Horizontal - Single Stage - Double Suction |
| MANUFACTURER: | Escher Wyss |
| SIZE DISCHARGE: | 85" |
| SIZE SUCTION: | - |
| RPM: | 214 |
| CFS: | 1161 |
| HEAD: | 250' |
| H.P. REQUIRED. | 38, 500 (44, 400 @ 230') |
| N s.: | 1935 |
| INSTALLED: | Feb., June, and Oct. 1958 |

| HRS OF OPERATION | | | | |
|---|---|---|---|---|
| | Pumping | I 10020 | II 9620 | III 11180 |
| | Generating | 7350 | 6490 | 8950 |
| | Condenser | 3350 | 3380 | 3640 |

| | |
|---|---|
| MIN. SUBMERGENCE: | 4.9' |
| NORMAL SUBMERGENCE: | 4.9' |
| MAX SUBMERGENCE: | 13' (only during floods) |
| REMARKS: | Submergence reduced to a minimum to reduce construction costs. Model tests indicated that pumps would be free of cavitation. |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | |
| MODEL ACTUAL: | Indicated 90% - Cavitation free |
| PROTOTYPE-GUARANTEED: | 89.5% Max. |
| PROTOTYPE-ACTUAL: | 87.0 at high and low head points<br>89.5 at Median Point |
| METHOD OF TEST: | Current Meters - Hutarew |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 85" |
| DIAMETER IMPELLER: | 141" |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 32.9" |
| MATERIAL CASING: | Cast steel with welded steel volute |
| MATERIAL IMPELLER: | Cast maganese steel |
| MATERIAL IMPELLER RINGS: | Cast Steel |
| MATERIAL-CASING RINGS: | Unknown |
| RADIAL CLEARANCE: | 1.2 mm |
| MATERIAL BALANCING RINGS: | None |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | - |
| BEARING: | 25.5" x 19.7" - Oil Pressure Lubricated |
| THRUST BEARING: | Kingsbury Type - 35.4" O.D. |

| | |
|---|---|
| TYPE OF PACKING: | Mechanical |
| MATERIAL OF PACKING: | 3 Carbon Rings |
| MATERIAL OF SLEEVE: | Bronze |
| CLEARANCE: | None |
| REMARKS: | Impeller plated with stainless steel in cavitation areas.<br><br>Clean Water injected with shaft packing running and at standstill. |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Horizontal synchronous exciter incorporated in rotor. 90% power factor, under-excited. |
| MANUFACTURER: | Siemans-Schuckert (Berlin) |
| H.P.: | Generating - 59,000 HP |
| R.P.M.: | 214 |
| VOLTAGE: | 10 KV |
| STARTING: | By turbine against closed valve |
| REMARKS: | Pump can be dewatered and uncoupled at full speed during generating cycle. Two units per transformer. |

TURBINE:

| | |
|---|---|
| TYPE: | Francis-Horizontal |
| MFG.: | Voith |
| HEAD: | 250' |
| R.P.M.: | 214 |
| H.P.. | 59,000 |
| REMARKS: | |

VALVES:

| | |
|---|---|
| INTAKE: | Stop Logs and Trash Rack |
| TYPE: | Sliding Gate |
| MANUFACTURER: | - |
| SIZE: | 17.3' x 16.6' |
| OPERATION: | Operated by Gantry crane during servicing only. |

DISCHARGE:

| | |
|---|---|
| TYPE: | Needle |
| MANUFACTURER: | Escher-Wyss |
| SIZE: | 106" |
| OPERATION: | |
| OPENING: | Oil Pressure with Air Vessel |
| CLOSING: | Water Pressure from Penstock |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |

REMARKS: Discharge valve constructed from steel plates. Stainless steel plating on parts subject to cavitation. Valves located 13" beyond crane reach. Must be moved on rails for servicing.

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Surface - One per unit |
| NO. & SIZE: | 3 x 12.5' (3800 mm) |
| LENGTH: | 2040' (610 MTS) plus 350 ft. of concrete lined tunnels at upper end. 440' @ 31.3% grade - rest at 8.4%. |

| | |
|---|---|
| MATERIAL: | Steel |
| TYPE OF UPPER GATE: | Unknown |
| SURGE TANK: | " |
| REMARKS: | |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Poluted River Water - Sludge but no abrasive material. |
| Ph: | Unknown |
| HARDNESS: | Presumably relatively soft. |

REMARKS: Chemical polution with domestic and industrial wastes. Detergent foam often reaches 3 ft. in tail water. However, no corrosion experienced. Paint still on Penstock interior.

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | Operation continuous as generator, Synchronous condenser or pumping. |
| STARTS/DAY: | - |
| HOURS OF OPERATION: | (See Page 2) |
| UNPLANNED OUTAGES: | One |
| CAUSE: | Leakage of coupling on oil Servometer. |
| INSPECTION SCHEDULE: | Once per year. |
| TIME REQUIRED: | One day (removal of upper half of suction elbow only). |
| OVERHAUL SCHEDULE: | Every 3 years (5000 hrs.) |
| TIME REQUIRED: | 5 weeks |
| IMPELLER CAVITATION: | Yes |

| | |
|---|---|
| SEAL RING WEAR: | None |
| NOISE LEVEL-START: | Noise at Cut-off head only. |
| NOISE LEVEL-RUN: | Relatively quiet. |
| VIBRATION: | No - only at cut-off. |
| REMARKS: | Stainless steel plating on impellers standing up well. Epoxy coating so far shows negative results. Original carbon rings in service for six (6) years and still in good condition. |

## GENERAL REMARKS

The State and City of Hamburg electricity supply was supplied only by steam power plants. When in the early fifties it was proposed to build a pumped storage plant to cover the peaks, provide night load for the steam plants and stand-by power, the steam people did not really believe that this was an economical proposition. They set a limit in first cost equal to that of a steam power plant which forced a "cheap" design -- apparently not always the economical proposition in the long run (see also Ffestiniog). Indeed the conditions at Geesthacht were rather unfavorable for a pumped storage plant because of the low head. The country around Hamburg is flat and they were able to find a hill of only 80 m in height. The whole geology, including the hill itself, consists of sand, which encountered special civil engineering problems. After six years of operation the plant has, however, proved its economical advantages and an extension doubling the capacity is under consideration.

### Pumps

The only trouble with the pumps is cavitation. They have to repair the impellers every three years (after approx. 5000 hours). Repair is done with the impeller in place, only the upper half of the suction elbow is removed. Such repair takes five weeks per day and night work, with two welders and two grinders. The impellers are of ordinary cast steel, (with stainless steel plating on entrance of blades), an affect of the trend to build a "cheap" plant. Welding is done with stainless steel electrodes of various types (18-25% Cr.). No significant difference has been noticed in standing up of these materials, but generally they stand much longer than the original steel cast. The repaired areas are nearly unaffected by the cavitation, the attack is restricted to the cast steel only. One can say that the cavitation damage would be negligible if the impellers were of stainless steel.

To eliminate the long welding repairs they try since some time to use plastic coatings and fillings instead. So far, the results were negative. The plastic firms said that they had not enough time for thoroughly cleaning and drying the impeller before applying the material and also for hardening out before going back into operation. Now they gave them two weeks in June this year for a proper application. They invited various manufacturers of plastic material to test their products. Every one or two impeller blades are repaired with other type plastics. They will now, after approx. ten weeks operation, inspect the impeller the first time.

Mr. Hoffmann is prepared to inform us about their findings by phone. However, conclusive results are not expected before one year of operation.

As they never dismantled a pump they do not know in what stage the wear rings are, but there is no indication of wear. So far they have, after six years, replaced the carbon rings only in one stuffing box and this was not really necessary.

The water is polluted by domestic and industrial wastes. There are still fish in the Elbe River, but they are not edible because of their taste as a result of the water contamination.

This contamination is, however, not aggressive. The paint in the penstocks is still in very good condition. There is certainly no sand in the water, only very fine sludge, which has no abrassive effect on the machinery.

## Turbines

There is also cavitation on the turbines at certain load ranges. This was improved by air introduction. No wear on the wear rings has been found (one runner was dismantled for cavitation repair).

## Valves

No problems with the needle valves on the pumps or with the butterfly valves on turbine inlet and penstock inlet at the reservoir, except with some controls.

## Other

During construction of the plant, at a heavy rain the water collected in the empty reservoir, overtopped and washed away a small sand dam, rushed out through the intake openings and down the partly completed penstocks and penstock foundation. The penstocks were heavily damaged, heavy concrete anchor blocks were turned over, and the lower parts of the power house were filled with sand.

Also, during construction they made sectional pressure tests of the penstocks. When they emptied the lower part of a penstock after a pressure test, the intermediate bulk head between upper and lower part became loose, the water from the upper part rushed down into the empty lower part and the upper part of the penstock collapsed completely due to the vacuum.

The plant is fully automatic and the units are remotely started and stopped from the cnntrol center in a steam power plant. Very little trouble with the controls and relays is reported.

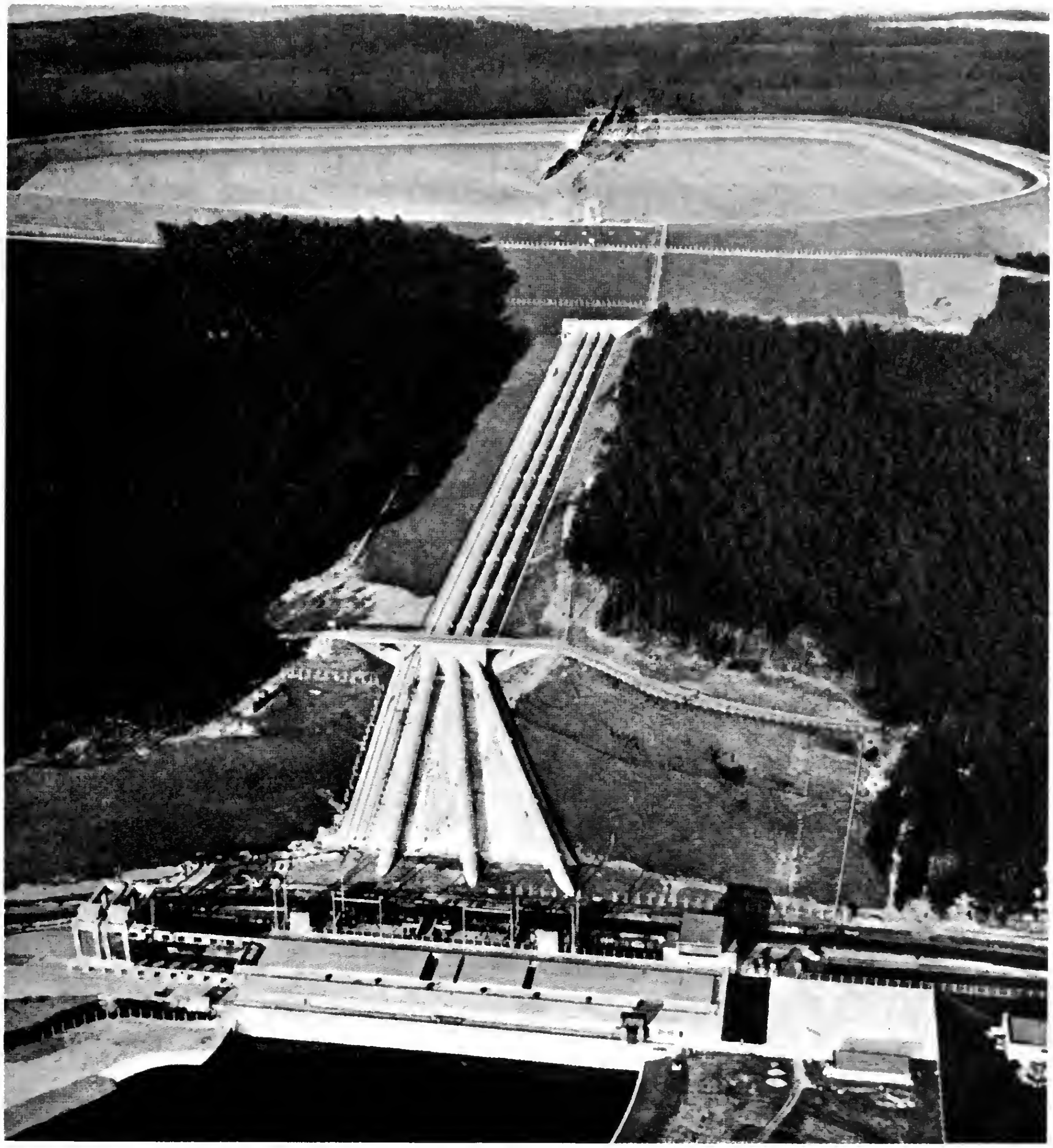
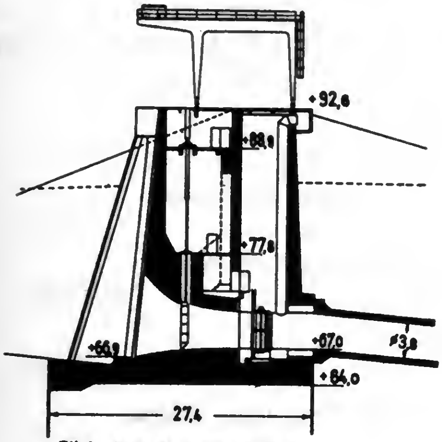


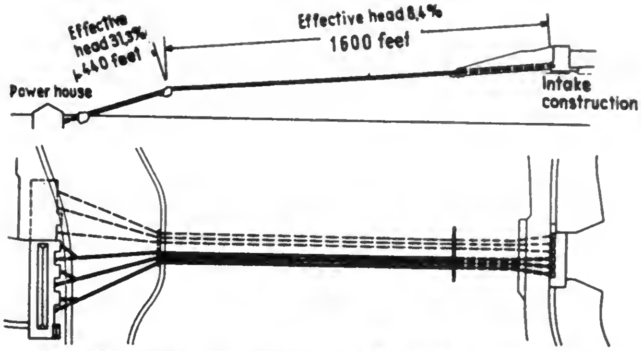
Fig. 31.1 - General view of Plant and Reservoir


Fig. 31.2 - Plant interior -- Escher Wyss pump in foreground.

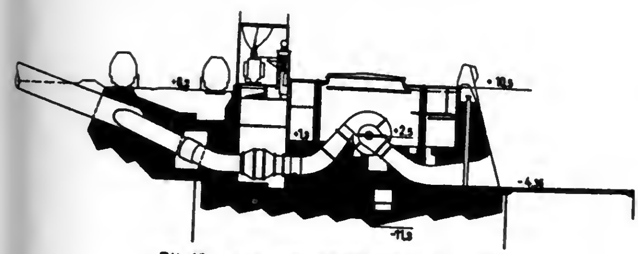
## Intake Construction

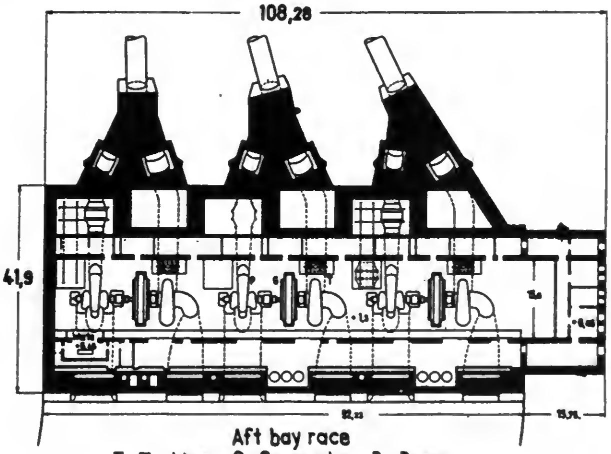


Jll. 4 Intake construction



Jll. 5 Pipe track, longitudinal section and ground plan


Jll. 10 Maschine house, section at pump



T: Turbine G: Generator P: Pump

Jll. 8 Maschine house, ground plan

Fig. 31.3 - Plant schematics.

PLANT NAME: HERVA

REPORT NO.: 32

| | |
|---|---|
| LOCATION-ALTITUDE: | East end of Sogne Fjord, Norway - 3280' |
| OWNER: | Ardal & Sundal Verk, S.A. (State of Norway) |
| ADDRESS: | Oslo, Norway |
| TYPE OF PLANT: | Pump Storage - Underground |
| SERVICE | Power for Aluminum Works |
| TYPE OF WATER: | Melted Glacial Water and Snow. |
| UNITS INSTALLED: | One Turbine - Generator - Pump Unit |
| HORSEPOWER: | 41,000 500 RPM |
| CFS: | 357 |
| STATIC HEAD: | 793 |
| PLANT STARTED: | 1963 |
| VISITED BY: | Hartmann - Cole |
| DATE: | October 7, 1964 (Meeting October 8) |
| PERSON(S) INTERVIEWED & TITLE(S): | Ole Tandberg - Resident Engineer<br>R. Nokleby - Chief Mech. Engineer<br>Jens Nybro-Hanson - Consulting Engineer<br>Thor Wested - Riva Representative |

REMARKS: Plant operated as a pump more or less continuously from end of May until end of August. Plant is located about 35 km, up a steep winding road (13% grade at times) from Skjölden, Norway, which is located at sea level at the end of Norway's longest Fjord, 196 km inland from the North Sea. Plant situated at a rather inaccessible, and very desolate and bleak location.

## PUMPS:

| | | | |
|---|---|---|---|
| TYPE: | One (1) Double Suction - 2-Stage Horizontal - 5-- PRM | | |
| MANUFACTURER: | RIVA (Milano) | | |
| SIZE DISCHARGE: | 51. 2" | | |
| SIZE SUCTION: | - | | |
| RPM: | 500 | | |
| CFS: | 328 | 357 | 403 |
| HEAD: | 910 | 870 | 811 |
| H.P. REQUIRED: | 37, 500 | 39, 400 | 41, 250 |
| N s.: | 1480 | | |
| INSTALLED: | 1962 | | |
| HRS. OF OPERATION | 2000± | | |

| | |
|---|---|
| MIN. SUBMERGENCE: | 26. 2' (8 M) |
| NORMAL SUBMERGENCE: | 59' (18 M) |
| MAX. SUBMERGENCE: | 69. 4' (22. 15 M) |
| REMARKS: | Pump takes water from small Lake and delivers it to another small Lake (artificial), where it either returns through Herva Plant or supplies water to Fortun Generating Plant, at Sea level or nearly so. |

## EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | No Model |
| MODEL ACTUAL: | No Model |
| PROTOTYPE-GUARANTEED: | 89.2% |
| PROTOTYPE-ACTUAL: | 91.5% |
| METHOD OF TEST: | 13 current meters in discharge tunnel. (*See remarks below) |

## CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 51.2" |
| DIAMETER IMPELLER: | 76.5" |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 23.6" |
| MATERIAL CASING: | Cast Steel - Welded Volute |
| MATERIAL IMPELLER: | Stainless Steel |
| MATERIAL IMPELLER RINGS: | None |
| MATERIAL-CASING RINGS: | Babbitt (per dwg. - doubtful) |
| RADIAL CLEARANCE: | Theoretically O |
| MATERIAL BALANCING RINGS: | None |
| MATERIAL INTERSTAGE SEAL: | Babbitt - No shaft sleeves |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | - |
| BEARING: | Babbitt - Ring Oiled |
| THRUST BEARING: | 27-1/2" O.D. Kingsbury type - Double acting. |

REMARKS: *Field test made by Riva in presence of Consultants Sept. 1963. Turbine efficiency measured at 95.2%, which appears rather high for such a turbine.

| | |
|---|---|
| TYPE OF PACKING: | 5 Carbon Rings |
| MATERIAL OF PACKING: | Carbon Rings |
| MATERIAL OF SLEEVE: | Stainless Steel |
| CLEARANCE: | - |
| REMARKS: | Clear water supply to shaft sleeves - runs continuously. |

MOTOR OR GENERATOR:

| | | |
|---|---|---|
| TYPE: | Synchronous - Exciter incorporated in rotor. | |
| MANUFACTURER: | AEG (Berlin) | |
| H.P.: | Turb. 48,000 | Pump 42,000 |
| R.P.M.: | 500 | |
| VOLTAGE: | 8000 | |
| STARTING: | Started by Turbine | |
| REMARKS: | Brought up to speed and synchronized by turbine - Then turbine unwatered. | |

TURBINE:

| | |
|---|---|
| TYPE: | Francis Type |
| MFG.: | Riva |
| HEAD: | Approx. 900' |
| R.P.M.: | 500 |
| H.P.: | - |
| REMARKS: | None |

## VALVES:

### INTAKE:

| | |
|---|---|
| TYPE: | Roller Gate |
| MANUFACTURER: | Kvaerner Brug |
| SIZE: | - |
| OPERATION: | Hydraulic |

### DISCHARGE:

| | |
|---|---|
| TYPE: | Needle |
| MANUFACTURER: | Riva |
| SIZE: | 51.25" (1300 mm) |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | Water Pressure |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | Discharge valve begins to open as pump comes up to speed and pump discharge pressure reaches penstock pressure. |

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | One - Size unknown |
| LENGTH: | Approx. 10,000' |

| | |
|---|---|
| MATERIAL: | - |
| TYPE OF UPPER GATE: | - |
| SURGE TANK: | None |
| REMARKS: | Discharge directly into upper reservoir. |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Glacial and snow - milky. |
| Ph: - | SOLIDS: Sandy at times. |
| HARDNESS: 0 ± | SALINITY: None |
| REMARKS: | Erosion effect expected from Turbine experience with similar water. |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | More or less continuous service from end of May until end of August, depending on water inflow. |
| STARTS/DAY: | Probably 100/year. |
| HOURS OF OPERATION: | Approx. 2000 |
| UNPLANNED OUTAGES: | None |
| CAUSE: | - |
| INSPECTION SCHEDULE: | None so far |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | None |
| TIME REQUIRED: | - |
| IMPELLER CAVITATION: | - |

| | |
|---|---|
| SEAL RING WEAR: | - |
| NOISE LEVEL-START: | A- 100 + 0 B- 100 + 3 C- 100 + 4.5 |
| NOISE LEVEL-RUN: | A- 90 + 3.5 B- 100 - 3.5 C-100 - 2 |
| VIBRATION: | Non Excessive |
| REMARKS: | Would consider this pump to be slightly above the average in noise. Very little cavitation noise. |

No difficulties experienced so far from pump but had trouble frequently from sticking or non-operation of relays of automatic system.

Pump has never been opened, strange as it may seem, considering their experience with erosion of Pelton turbines with the same water. Expect to inspect pump in October 1964.

Excessive leakage from stuffing box on pump.

Some difficulty experienced with inter-polar connections on generator - Being repaired by AEG.

## GENERAL REMARKS

The Herva and Fortun plants are situated at the end of one bay of the Sogne Fjord in the southwest of Norway. Owner of these plants is the Ardal & Sundal Verk AS, an aluminum company. The aluminum works are situated at Ardal, at another bay of the Sogne Fjord, where there is a third power plant called Tyin. The power produced is used for the aluminum production. A very small percentage is delivered to the towns along the Sogne Fjord, in case these are short of power which they normally produce in their own little hydro-electric stations. The Ardal & Sundal Verk is a limited company, however, all shares are held by the Norwegian state.

The Tyin power station was built during the war. The Fortun power station is operating since 1958, and Herva is the newest station, operating since 1962. Herva is situated nearly 1000 m a. s. l. Head water of this plant are two storage lakes with a level difference of 26 m. The turbine can be operated from both lakes, however, pumping is only possible to the lower one. The tail water of the Herva station is the head water of the Fortun power station. Herva, Fortun and Tyin are underground stations with underground penstocks and tunnels.

### Herva

They had no troubles in Herva caused by the pump. Regarding material we could not get complete information as they had only a few drawings at the plant. Mr. Tandberg said that all impellers are of stainless steel, however, the drawing indicates different material for the first stage impellers and for the second stage impellers. Also with the wear rings we are not sure whether the information given by Mr. Tandberg is correct, that the stationary rings have a babbitt lining. This would be a rather unique feature. A complete dismantling of the pump is scheduled for October 1964 and Mr. Tandberg promised to send us a short note about their findings. The main reason for this dismantling is that the guarantee period is expiring. Astonishing enough, they have never opened the manholes on the suction elbows to look at the suction impellers during the two years they are operating now. When the pump was started for our noise and vibration measurements, very slight cavitation cracks were audible at the suctions. Mr. Tandberg said that this was not the case during the summer. Maybe he did not notice it or, another possibility, the impellers are worn by sand erosion and that the now rough blade surface leads to cavitation. In any case, the cavitation noise was very little, and we believe that it will not at all result in any visible damage on the impellers. There are, however, indications of considerable sand in the water. One day the oil water accumulator for the pump discharge valve failed and they found in the water cylinder which is connected to the pump discharge, a large amount of sand and even small stones up to a diameter of approximately 1". Obviously, the sand must have gone through the pump.

One of the stuffing boxes, which are provided with filtered water, is leaking heavily. They said that this was the case right from the beginning and it shall be repaired during the forthcoming dismantling of the pump.

The pump is running all right, but certainly not exceptionally smooth and quiet as has been reported. If any judgment should be made, we would rank this pump with the more noisy ones. This refers to shut-off as well as to normal pumping operation. No troubles were reported with respect to the turbine except a rather heavy cavitation and vibration in a certain load range (18 to 20 MW). As the turbine is operated at full load, normally they do not bother about that.

They had no troubles with the valves, i. e., neither with the needle valve at the pump nor with the spherical valve of the turbine.

With the generator they had bearing troubles, and they say bearing troubles are a significant feature of all their AEG-generators.

They have considerable trouble with all the control and automatic systems. Especially the limit switches they have installed are failing frequently. This was illustrated also at the pump start they made for us, which was delayed for two hours by a failing limit switch, and the same thing happened when they started the pump for Mr. Winn and Mr. Sutherland on the occasion of their visit. We had the impression that the ventilating and air conditioning system in Herva is very primitive. If the unit is not operated for a longer period, the temperature in the powerhouse may drop below 10°C as the heating is provided only by hot air from the generator. We felt rather uncomfortable in this station and it may well be that their control troubles are partly caused by the humid atmosphere and water condensation in the appartus. A rather confusing chapter is the efficiencies they have measured in Herva. 91.5% would be very good for a pump of this size, but 95.2% maximum efficiency for the turbine is certainly too high. We do not remember any case of a turbine efficiency higher than 95.0%. Some very high values close to 95.0% were given in the literature.

Fortun

Fortun has six units of 40 MW with Pelton turbines of Voith manufacture. Generators are from AEG. The plant is operating under the rather high head of 900 m. In spite of that, they had no troubles with the turbines and no wear on the runners as long as the plant got water only from two large storage lakes. One and one-half years ago they brought an additional water collecting tunnel into operation. This tunnel goes along a valley and collects various creeks. The water of these creeks goes into the tunnel without any de-sanding installations. From that moment on they got considerable sand into the water and excessive wear on the turbines. The buckets have lost nearly 1/2 of the wall thickness, i. e., approx. 1/2", and it should be noted that these impellers are of stainless steel. They have to ship the impellers back to Voith for a complete re-welding and subsequent annealing, a very costly procedure. They have also ordered new runners with G. Fischer, Schaffhausen, and will try now a new alloy, 14% Cr and 4% Ni, which is said to be harder than the usual 13 or 14% Cr steel. They are, however, well aware that the problem is to get rid of the sand, and they are studying how they could do that. As the valley is very steep, they will probably have to build de-sanders under ground. They are, of course, very desparate about this situation, but they do not at all blame the turbine manufacturer, because it is evident that only the sand is the reason for their trouble. As already mentioned before, there was no wear on the turbines before they got the sand into the system. They said also that they have no wear on the Pelton turbines at Tyin, also Voith manufacture where the water comes from a very large storage lake. We believe that Fortun is a very instructive sample for the sand and wear problem.

Fig. 32.1

Type of Terrain at plant location

Fig. 32.2

Eastern end of Sogne Fjord

Fig. 32.3

Turbine, Generator, and Pump

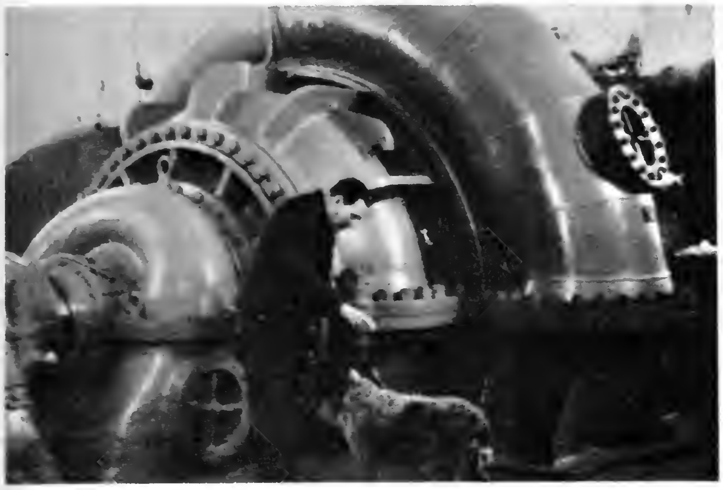


Fig. 32.4

View of Pump
(Also Ole Tandberg
and his dog.)

Fig. 32.5

Operating Mechanism
of Riva Spherical Valve
at Turbine Inlet

## Vibration Records

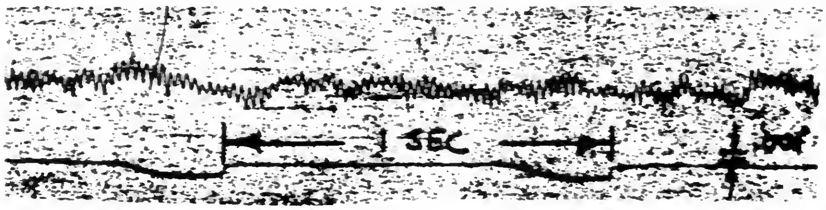
Ardal and Sundal Verk, Oslo, Norway

Plant : Herva (underground power house)

Units : one, 2-stage, double flow, horizontal pumps;
39,500 HP, 357 cfs, 868 ft, 500 RPM.

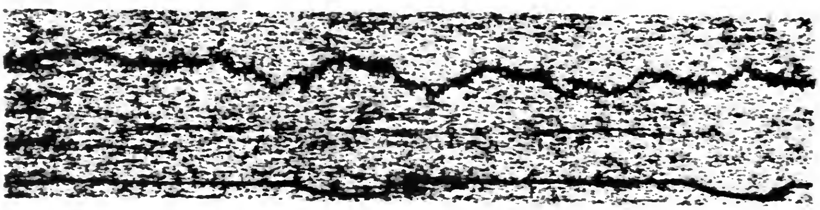
Records taken: October 7, 1964

Measured Point Volute




1. Pump start

2. Full speed, discharge valve closed



3. Discharge valve begins to open

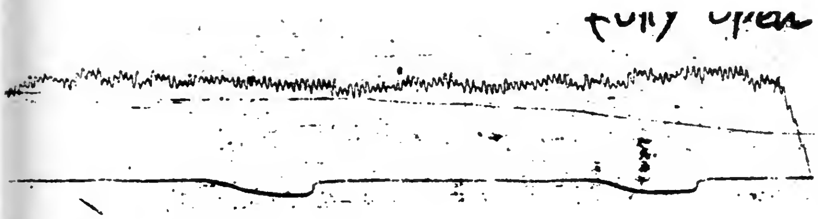
| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 3600 | .0018 |
| 10,200 | .0016 |
| 4800 | .0010 |

Figure 32-6

Vibration Records (cont.)

Ardal and Sundal Verk, Oslo, Norway

Plant : Herva (underground power house)



4. Fully open

5. Normal pumping

| Frequency c.p.m. | Average Amplitude inches |
|---|---|
| 5600 | .0008 |
| 7500 | .0007 |

Figure 32-7

# PART II

# INVESTIGATION OF PUMPING PRACTICE IN THE UNITED STATES

## INVESTIGATION OF PUMPING PRACTICE IN THE UNITED STATES

### 1. INTRODUCTION:

In conjunction with the investigation of high speed pumping practice in Europe, an investigation of some of the larger pumping stations in the United States was made by members of the Daniel, Mann, Johnson, & Mendenhall Staff.

All American pumping stations visited are of the single-stage, single-flow vertical type and, therefore, correspond more closely to the three-lift concept considered as one of the alternates at Tehachapi. Even the three-lift concept of Tehachapi, involving lifts of approximately 650 ft. per lift involves heads considerably higher than is generally experienced in American practice.

A total of eleven pumping stations, containing 73 pumps, were visited and the operating personnel interviewed, particularly with regard to reliability factors, maintenance practice, experience with various construction materials and other pertinent data.

A detailed report, covering each plant visited, is incorporated herein.

For a detailed evaluation of the survey see comments in Chapter 2, Volume II.

### 2. SUMMARY OF PLANTS VISITED:

The plants visited varied in heads of from 85 feet to 450 feet, in capacities from 200 cfs to 3900 cfs, and in power requirements from 4300 HP to 250,000. Rotative speeds varied from 105.9 to 450 RPM. All pumps were vertical single suction, single-stage.

Four of the plants visited, Lewiston, Hiwassee, Buchanan Dam and Taum Sauk were pump storage plants and, although relatively high in horsepower rating and capacity, had little or no operating experience record, less than 5000 hours maximum. Those with any service factor at all were of low head, 120 feet maximum.

Five of the stations observed were those operated by the Metropolitan Water District in the Colorado River Aqueduct. These 45 pumps have from 35,000 to 100,000 hours of operation with a high service factor and, therefore, their operating experience is fairly valuable. However, the maximum rating is only 12,500 HP, and maximum head and capacity are under anything appropriate for the Tehachapi job.

The Grand Coulee pumps present an example of station of high power capacity and a fairly extensive time of operation, but the head is relatively low in comparison to any of the Tehachapi concepts. The Tracy pumps have operated many hours, but here again the head is low.

None of the American pumping plants are what might be termed "underground" stations.

All plants visited, except those of the Metropolitan Water District, are operated as pumps either seasonally or periodically. The Metropolitan Water District keeps one unit per station (out of nine) down all the time for repair and maintenance.

Pertinent information which was collected is shown on Plates III, IV and V of this report.

A chart showing in graphical form the comparison of various pertinent parameters is shown on Plate II of this report.

## TABLE IA

## AMERICAN PUMPING STATIONS

| No. | Name | No. Pumps | CFS | H | HP | Operating Hours |
|---|---|---|---|---|---|---|
| 1A-5A | Colorado Aqueduct | 45 | 200 | 300<br>146<br>440 | 9000<br>4300<br>12, 500 | 30, 000-<br>100, 000 |
| 6A | Lewiston | 12 | 3400 | 85 | 37, 500 | 4, 062 |
| 7A | Hiwassee | 1 | 3900 | 205 | 102, 000 | None |
| 8A | Tracy | 6 | 850 | 197 | 22, 500 | 35, 000 |
| 9A | Grand Coulee | 6 | 1350 | 311 | 65, 000 | 20, 000 |
| 10A | Buchanan Dam | 1 | 835 | 120 | 13, 450 | 4, 500 |
| 11A | Taum Sauk | 2 | 2450 | 810 | 250, 000 | Few |

**PLANT NAME:** INTAKE (MWD)

**REPORT NO.:** 1A

| | |
|---|---|
| LOCATION-ALTITUDE: | Lake Havasu, California - 450' |
| OWNER: | Metropolitan Water District of Southern California |
| ADDRESS: | Los Angeles |
| TYPE OF PLANT: | Pumping only - Surface |
| SERVICE | Water supply for MWD |
| TYPE OF WATER: | Clean Lake water |
| UNITS INSTALLED: | Nine one-stage, single-flow pumps driven by 900 HP - 400 RPM motors. |
| HORSEPOWER: | 9 x 9000 =81,000 (400 RPM) |
| CFS: | 6 x 200 + 3 x 215 |
| STATIC HEAD: | 291' |
| PLANT STARTED: | Mfg. 1-3 (1937); 4-5 (1954); 6- (1956); 7-9 (1958)<br>Started January 1939 (three units) |
| VISITED BY: | Cole-Hall-Benz-Westman-Bowerman |
| DATE: | November 9, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Joe Reider, Gen. Superintendent<br>Ed Hines, Plant Superintendent<br>Harry Stroal, Shift Operator |
| REMARKS: | Eight units deliver approximately 1600 CFS to Gene Reservoir.<br><br>Building 40' x 184' |

## PUMPS:

| | | | |
|---|---|---|---|
| TYPE: | Single-stage, single-suction Vertical | | |
| MANUFACTURER: | Byron Jackson | | |
| SIZE DISCHARGE: | 42" | | |
| SIZE SUCTION: | 72" | | |
| RPM: | 400 | | |
| CFS: | 6 x 200; | 2 x 215; | 1 x 210 |
| HEAD: | 294 | 315 | 315 |
| H.P. REQUIRED: | 7350 | 8500 | 8100 |
| N s.: | 1680 | 1665 | 1640 |
| INSTALLED: | 1937 | 1958 | 1956 |
| HRS. OF OPERATION | Nos. 1-3 | 100,000 | |
| | 4-5 | 55,000 | |
| | 6-9 | 30,000 | |
| | (Estimated) | | |
| MIN. SUBMERGENCE: | 10' | | |
| NORMAL SUBMERGENCE: | 15' - 20' | | |
| MAX. SUBMERGENCE: | 20' | | |
| REMARKS: | - | | |

## EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | 90.9 |
| PROTOTYPE-GUARANTEED: | - |
| PROTOTYPE-ACTUAL: | 91.2 |
| METHOD OF TEST: | Salt Velocity |

## CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 42" |
| DIAMETER IMPELLER: | 78-5/8 |
| DIAMETER EYE: | 40" |
| DIAMETER SHAFT: | 20" |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | 1-5: Bronze; 6-9: Stainless Steel |
| MATERIAL IMPELLER RINGS: | Old: Cast Iron; New: Stainless |
| MATERIAL-CASING RINGS: | Old: CI Brz. Inserts; New: Cast Steel |
| RADIAL CLEARANCE: | .0.5" (.020" - .025") |
| MATERIAL BALANCING RINGS: | Same |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | None |
| BEARING: | 20-1/8 x 25" Pump Guide |
| THRUST BEARING: | Kingsbury - six pads 33" OD in motor. |

## VALVES:

### INTAKE:

| | |
|---|---|
| TYPE: | Gates |
| MANUFACTURER: | - |
| SIZE: | 6' x 6' |
| OPERATION: | Crane |

### DISCHARGE:

| | |
|---|---|
| TYPE: | Cone - Tapered |
| MANUFACTURER: | 1-5: S. Morgan Smith; 4-9: Willamette Davis Design |
| SIZE: | 42" x 60" |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | 60 sec. |
| EMERGENCY: | 90% - 2.8 sec.; 10% - 6 sec. |
| REMARKS: | Each valve has its own accumulator. |
| | Tapered construction - 8" bypass. |

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Surface |
| NO. & SIZE: | Three 10' (6' branches from pumps) |
| LENGTH: | 946' |

| | |
|---|---|
| TYPE OF PACKING: | Packed Stuffing Box |
| MATERIAL OF PACKING: | Lead foil - Crane Super Seal No. 1<br>"All Pack" - Garlock or Crane |
| MATERIAL OF SLEEVE: | Stainless |
| CLEARANCE: | None - Slight Leakage |
| REMARKS: | |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical synchronous - Direct connected exciter - 95% PF |
| MANUFACTURER: | 1-5: GE; 6-9: Elliot |
| H. P. | 9000 |
| RPM: | 400 |
| VOLTAGE: | 6900 |
| STARTING: | Direct - full voltage against closed valve. |
| REMARKS: | Amortisseur windings loosened after 15 years.<br>Starting time - 8 seconds |

TURBINE:

| | |
|---|---|
| TYPE: | None |
| MFG: | - |
| HEAD: | - |
| RPM: | - |
| H. P.: | - |
| REMARKS: | - |

| | |
|---|---|
| MATERIAL: | Steel (first riveted) |
| TYPE OF UPPER GATE: | Sliding gates (3) |
| SURGE TANK: | 60' x 60' high |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Good - clear lake water |
| Ph: | 8 to 8.4 |
| HARDNESS: | Hard |
| REMARKS: | See analysis attached |

MAINTENANCE AND OPERATION:

| | | | |
|---|---|---|---|
| OPERATING SCHEDULE: | - | | |
| STARTS/DAY: | - | | |
| HOURS OF OPERATION: | Nos. 1-3 | 100,000 | |
| | 4-5 | 55,000 | (Estimated) |
| | 6-9 | 30,000 | |
| UNPLANNED OUTAGES: | Two - 1961 | | |
| CAUSE: | Plane hit line - faulty pin in 230 kV line. | | |
| INSPECTION SCHEDULE: | - | | |
| TIME REQUIRED: | - | | |
| OVERHAUL SCHEDULE: | - | | |
| TIME REQUIRED: | - | | |
| IMPELLER CAVITATION: | - | | |

*Whitsett Intake Pumping Plant on California shore of Lake Havasu, two miles above Parker Dam. Here the water is lifted 291 feet from the lake and started on its long journey across the State of California to serve the increasing millions in The Metropolitan Water District of Southern California.*

Fig. 1A-1 - View of Intake Station

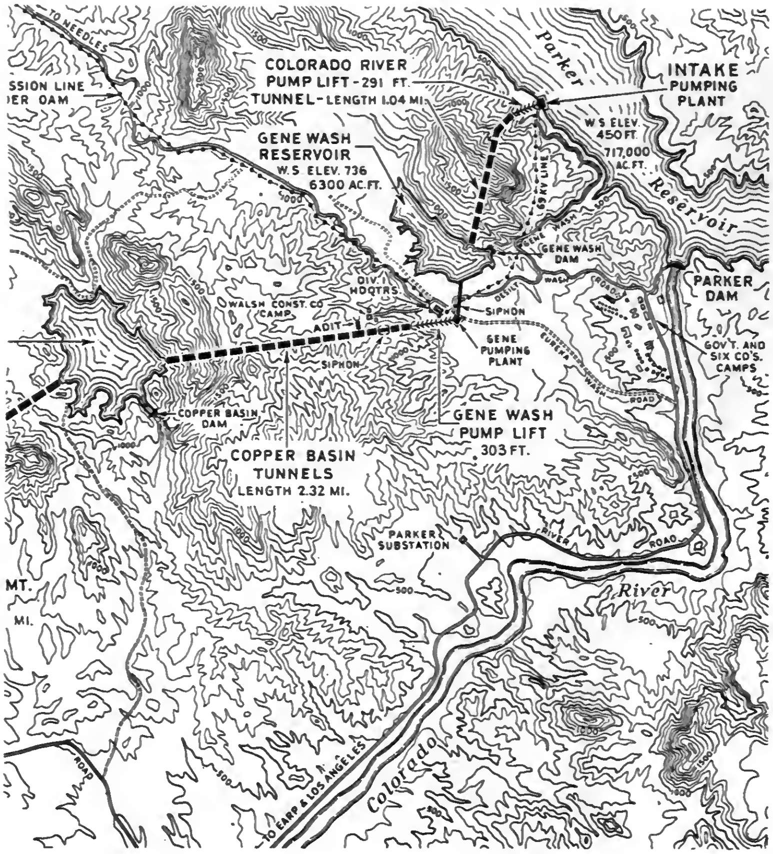



Fig. 1A-2 - Map of Intake System

Fig. 1A-3 - Interior view of Station

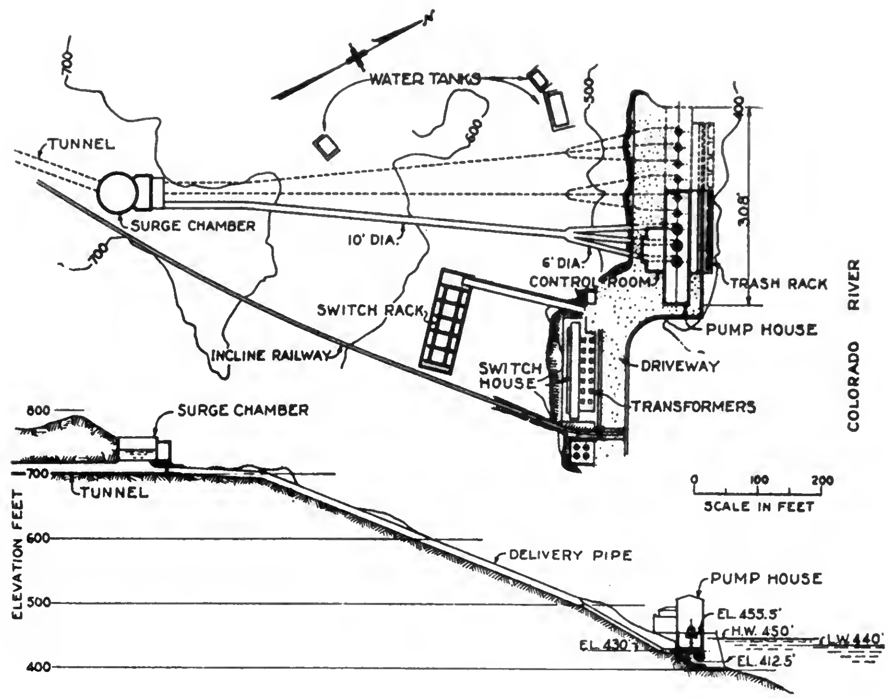



Fig. 1A-4 - Plan and Profile of Intake Plant

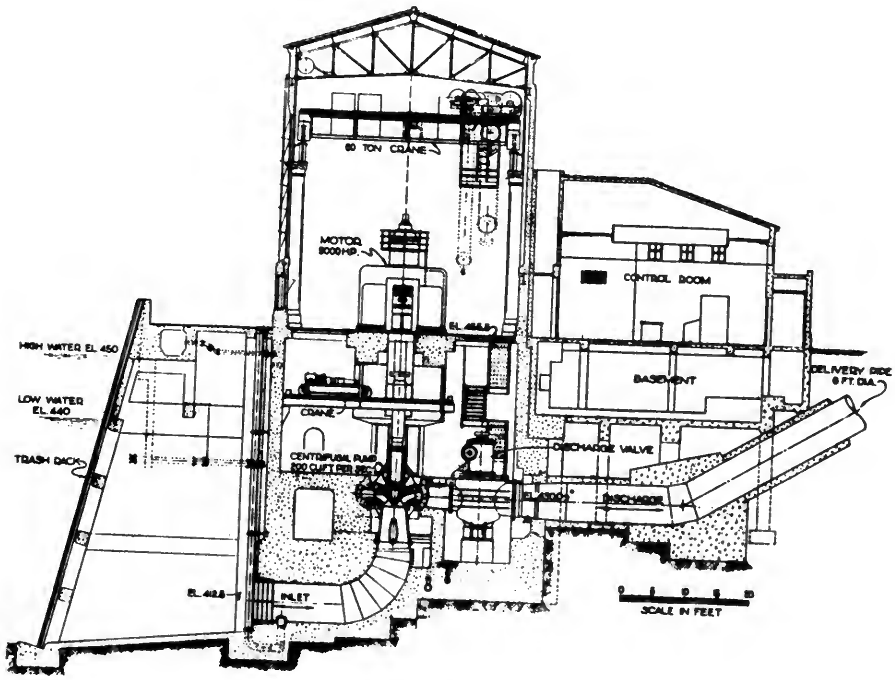



Fig. 1A-5 - Cross Section through Intake Plant.

PLANT NAME: GENE (MWD)

REPORT NO.: 2A

| | |
|---|---|
| LOCATION-ALTITUDE: | Near Parker Dam - 740' |
| OWNER: | Metropolitan Water District of Southern California |
| ADDRESS: | Los Angeles |
| TYPE OF PLANT: | Surface |
| SERVICE | Pumping only - water supply for MWD. |
| TYPE OF WATER: | Clear lake water. |
| UNITS INSTALLED: | Nine vertical pumping units. |
| HORSEPOWER: | 9 x 9000 (400 RPM) |
| CFS: | 6 x 200; 3 x 215 |
| STATIC HEAD: | 303' |
| PLANT STARTED: | Jan. 1939 (3 units) |
| VISITED BY: | Cole-Hall-Benz-Westman-Bowerman |
| DATE: | November 9, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Joe Reider, Gen. Supt.<br>Norm Bremer, Shift Operator<br>Walt Smith, Master Mechanic |
| REMARKS: | Plant lifts approximately 1600 CFS from Gene Reservoir to Copper Canyon Reservoir.<br>Building 39-1/2' x 179-1/2' |

PUMPS:

| | | | | |
|---|---|---|---|---|
| TYPE: | Single-stage, single-suction vertical | | | |
| MANUFACTURER: | Byron Jackson | | | |
| SIZE DISCHARGE: | 42" | | | |
| SIZE SUCTION: | 72" | | | |
| RPM: | 400 | | | |
| CFS: | 1-6: | 200; | 7-9: | 215 |
| HEAD: | | 310 | | 310 |
| H.P. REQUIRED: | | 7750 | | 8130 |
| N s.: | | 1620 | | 1680 |
| INSTALLED: | January 1939 | | | |
| HRS. OF OPERATION | No. 1-3 | 100,000 | | |
| | 4-5 | 55,000 | | |
| | 6-9 | 30,000 | | |
| | (Estimated) | | | |
| MIN. SUBMERGENCE: | - | | | |
| NORMAL SUBMERGENCE: | 20' | | | |
| MAX. SUBMERGENCE: | - | | | |
| REMARKS: | CFS Per Meters: | | | |

| | |
|---|---|
| No. 1 - | Down (210) |
| 2 - | 208 |
| 3 - | 220 |
| 4 - | 224 |
| 5 - | 212 |
| 6 - | 214 |
| 7 - | 233 |
| 8 - | 250 |
| 9 - | 232 |
| Totals | 1793 |

## EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | 90. 1 |
| PROTOTYPE-GUARANTEED: | - |
| PROTOTYPE-ACTUAL: | 91. 2 |
| METHOD OF TEST: | - |

## CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 42" |
| DIAMETER IMPELLER: | 78-5/8" |
| DIAMETER EYE: | 40" |
| DIAMETER SHAFT: | 20" |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | 1-5: Bronze; 6-9 Stainless |
| MATERIAL IMPELLER RINGS: | Old: CI; New: Stainless |
| MATERIAL-CASING RINGS: | Old: CI - Bronze inserts; New: Cast Steel |
| RADIAL CLEARANCE: | .015 (.020" - .025") |
| MATERIAL BALANCING RINGS: | Same |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | None |
| BEARING: | 20-1/8 x 25" |
| THRUST BEARING: | Kingsbury - 33" OD - 6 Pads |

| | |
|---|---|
| TYPE OF PACKING: | Garlock |
| MATERIAL OF PACKING: | Hemp - Lead |
| MATERIAL OF SLEEVE: | Stainless |
| CLEARANCE: | None |
| REMARKS: | Slight leakage |

<u>MOTOR OR GENERATOR:</u>

| | |
|---|---|
| TYPE: | Vertical synchronous - Direct connected exciter |
| MANUFACTURER: | 1-7: GE; 7-9: Elliot |
| H. P. | 9000 |
| RPM: | 400 |
| VOLTAGE: | 6900 |
| STARTING: | Direct - Full voltage |
| REMARKS: | Closed valve - 8 seconds to come up to speed |

<u>TURBINE:</u>

| | |
|---|---|
| TYPE: | None |
| MFG: | - |
| HEAD: | - |
| RPM: | - |
| H. P.: | - |
| REMARKS: | - |

## VALVES:

### INTAKE:

| | |
|---|---|
| TYPE: | Butterfly |
| MANUFACTURER: | - |
| SIZE: | 60" |
| OPERATION: | Mechanically or electrically |

### DISCHARGE:

| | |
|---|---|
| TYPE: | Tapered cone |
| MANUFACTURER: | 3 - S. Morgan Smith<br>6 - Willamette (Davis Design) |
| SIZE: | 42" x 60" |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | 60 seconds |
| EMERGENCY: | 90% - 2.8 seconds<br>10% - 6 seconds |
| REMARKS: | Eight (8) bypass with check valve. |

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Surface |
| NO. & SIZE: | Three 10' (6' branches to pumps) |
| LENGTH: | 2202' |

| | |
|---|---|
| MATERIAL: | Steel (First one rivited) |
| TYPE OF UPPER GATE: | Three sliding - 9' x 9' with 20" bypass |
| SURGE TANK: | 36' x 30' high |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Good - Lake Water |
| Ph: | - |
| HARDNESS: | (See lab report) |
| REMARKS: | - |

MAINTENANCE AND OPERATION:

| | | | |
|---|---|---|---|
| OPERATING SCHEDULE: | - | | |
| STARTS/DAY: | - | | |
| HOURS OF OPERATION: | Nos. | 1-3 | 100,000 |
| | | 4-5 | 55,000 |
| | | 6-9 | 30,000 |
| | | (Estimated) | |
| UNPLANNED OUTAGES: | - | | |
| CAUSE: | - | | |
| INSPECTION SCHEDULE: | - | | |
| TIME REQUIRED: | - | | |
| OVERHAUL SCHEDULE: | - | | |
| TIME REQUIRED: | - | | |
| IMPELLER CAVITATION: | - | | |

Fig. 2A-1 - View of Gene Station

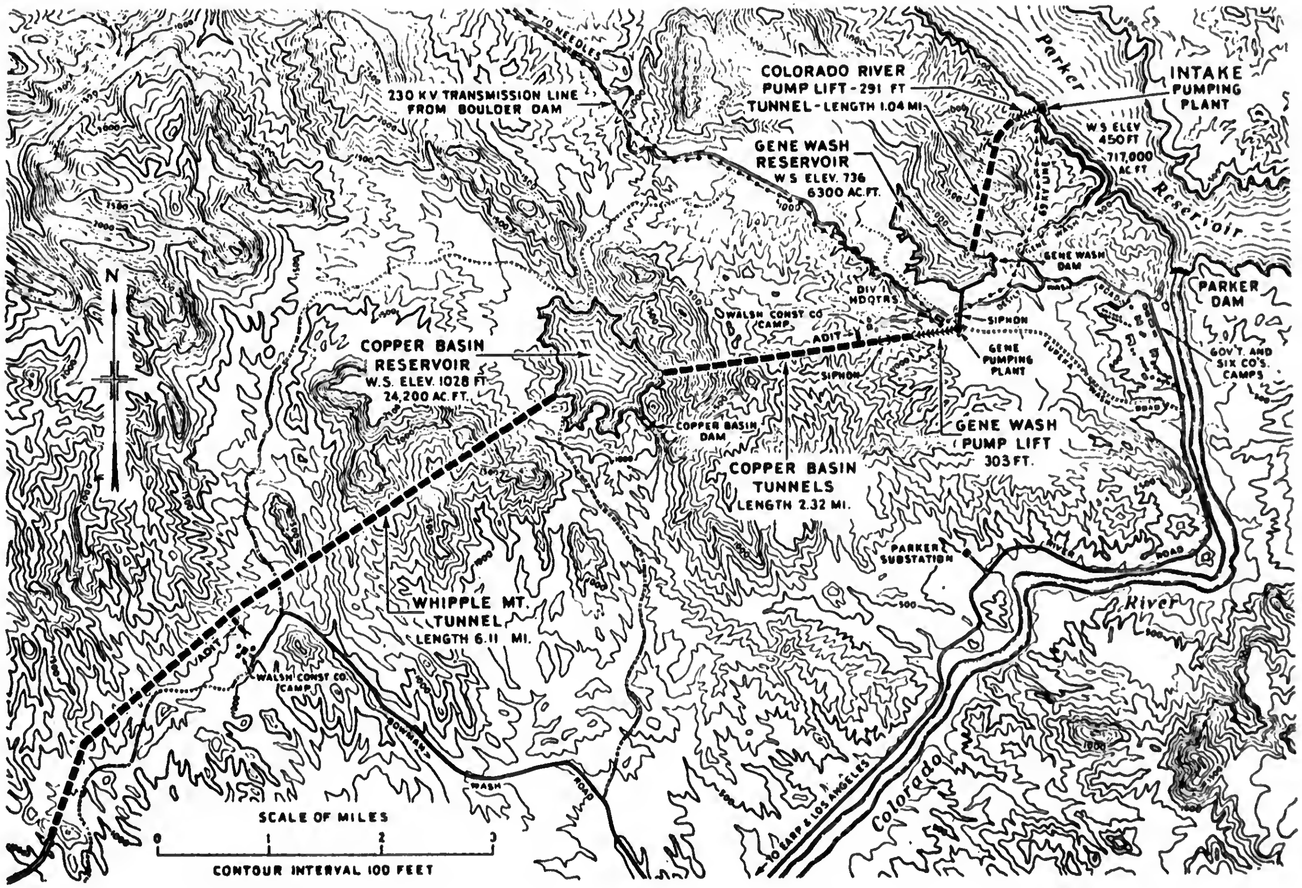



Fig. 2A-2 - Map of Location

PLANT NAME: IRON MOUNTAIN

REPORT NO.: 3A (MWD)

| | |
|---|---|
| LOCATION-ALTITUDE: | Approx. 70 mi. West of Parker Dam - 888' |
| OWNER: | Metropolitan Water District of Southern California |
| ADDRESS: | Los Angeles |
| TYPE OF PLANT: | Surface |
| SERVICE | Pumping only - Transportation of Colorado River water to MWD. |
| TYPE OF WATER: | Clear lake water, plus sand and dust acquired en route. |
| UNITS INSTALLED: | Nine vertical pumping units and motors. |
| HORSEPOWER: | 9 x 4300 (300 RPM) |
| CFS: | 1-6: 200; 7-9: 224 |
| STATIC HEAD: | 144' |
| PLANT STARTED: | Jan. 1939 (3 units) |
| VISITED BY: | Cole-Hall-Benz-Westman-Bowerman |
| DATE: | Nov. 10, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Joe Reider, General Superintendent<br>Mr. Sanborn, Station Chief |
| REMARKS: | Station takes water direct from canal and delivers it to Iron Mountain tunnel.<br><br>Building 39-1/2 x 179' |

PUMPS:

| | | | | |
|---|---|---|---|---|
| TYPE: | Vertical - single-stage, single-suction | | | |
| MANUFACTURER: | Allis-Chalmers | | | |
| SIZE DISCHARGE: | 48" | | | |
| SIZE SUCTION: | 72" | | | |
| RPM: | 300 | | | |
| CFS: | 1-6: | 200 | 7-9: | 224 |
| HEAD: | | 146' | | 150' |
| H.P. REQUIRED: | | 3750 | | 4220 |
| N s.: | | 2140 | | 2210 |
| INSTALLED: | January 1939 | | | |
| HRS. OF OPERATION | Nos. | 1-3 | 100,000 | |
| | | 4-5 | 55,000 | |
| | | 6-9 | 30,000 | |
| | | (estimated) | | |
| MIN. SUBMERGENCE: | - | | | |
| NORMAL SUBMERGENCE: | 16' | | | |
| MAX. SUBMERGENCE: | - | | | |

REMARKS: CFS per Meters:

| | |
|---|---|
| No. 1 - | Down |
| 2 - | 144 |
| 3 - | 175 |
| 4 - | 185 |
| 5 - | 190 |
| 6 - | 188 |
| 7 - | 238 |
| 8 - | 238 |
| 9 - | 250 |
| Total | 1608 |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | 91.2 |
| PROTOTYPE-GUARANTEED: | - |
| PROTOTYPE-ACTUAL: | 91.4 |
| METHOD OF TEST: | - |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 48' |
| DIAMETER IMPELLER: | 74-1/8" |
| DIAMETER EYE: | 40-7/8 |
| DIAMETER SHAFT: | 20-5/16 (taper fit) |
| MATERIAL CASING: | Cast steel |
| MATERIAL IMPELLER: | 6 Bronze; 3 stainless |
| MATERIAL IMPELLER RINGS: | Cast Iron Stainless |
| MATERIAL-CASING RINGS: | Bronze Inserts - Steel |
| RADIAL CLEARANCE: | .015" (.020" - .025") |
| MATERIAL BALANCING RINGS: | Same |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | None |
| BEARING: | 20-1/8 x 12" |
| THRUST BEARING: | In motor - 33" OD |

| | |
|---|---|
| TYPE OF PACKING: | - |
| MATERIAL OF PACKING: | - |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical - Synchronous - Direct connected exciter - 95% PF. |
| MANUFACTURER: | Allis-Chalmers |
| H. P. | 4300 |
| RPM: | 300 |
| VOLTAGE: | 6900 |
| STARTING: | Direct full voltage |
| REMARKS: | Against closed valve |

TURBINE:

| | |
|---|---|
| TYPE: | None |
| MFG: | - |
| HEAD: | - |
| RPM: | - |
| H. P.: | - |
| REMARKS: | - |

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | Butterfly |
| MANUFACTURER: | Willamette |
| SIZE: | 60" |
| OPERATION: | Mechanical - Electric Motor |

DISCHARGE:

| | |
|---|---|
| TYPE: | Cone (Tapered) |
| MANUFACTURER: | S. Morgan Smith |
| SIZE: | 48" x 60" |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | 60 Sec. |
| EMERGENCY: | 90% - 3 sec.; 10% - 6 sec. |
| REMARKS: | 8" bypass with check valve. |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Surface |
| NO. & SIZE: | Three 10' (6' branches to pumps) |
| LENGTH: | 689' |

| | |
|---|---|
| MATERIAL: | Steel (1st riveted) |
| TYPE OF UPPER GATE: | Three sliding gates 9' x 9' with 20" bypass |
| SURGE TANK: | Transition only |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Good - lake water |
| Ph: | (see analysis) |
| HARDNESS: | - |
| REMARKS: | Havasau Lake water plus sand and dust collected en route. |

MAINTENANCE AND OPERATION:

| | | | |
|---|---|---|---|
| OPERATING SCHEDULE: | - | | |
| STARTS/DAY: | - | | |
| HOURS OF OPERATION: | No. | 1-3 | 100,000 |
| | | 4-5 | 55,000 |
| | | 6-9 | 30,000 |
| | | (Estimated) | |
| UNPLANNED OUTAGES: | - | | |
| CAUSE: | - | | |
| INSPECTION SCHEDULE: | - | | |
| TIME REQUIRED: | - | | |
| OVERHAUL SCHEDULE: | - | | |
| TIME REQUIRED: | - | | |
| IMPELLER CAVITATION: | - | | |

PLANT NAME: EAGLE MOUNTAIN

REPORT NO.: 4A (MWD)

| | |
|---|---|
| LOCATION-ALTITUDE: | 110 mi. of aqueduct West of Parker Dam - 966' |
| OWNER: | Metropolitan Water District of Southern California |
| ADDRESS: | Los Angeles |
| TYPE OF PLANT: | Surface |
| SERVICE | Pumping only. Transportation of water from Colorado River to MWD. |
| TYPE OF WATER: | Lake Water - Clear |
| UNITS INSTALLED: | Nine vertical pump and motor units. |
| HORSEPOWER: | 9 x 12,500 (450 RPM) |
| CFS: | 1-4: 200; 5-6: 213.84 (96,000 GPM);<br>7-9: 219.46 (98,500 GPM) |
| STATIC HEAD: | 438' |
| PLANT STARTED: | Jan. 1939 (3 units) |
| VISITED BY: | Cole-Hall-Benz-Westman-Bowerman |
| DATE: | November 10, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | J. A. Reider, General Superintendent<br>Oliver Thompson, Station Chief<br>Joe Shill, Electric Test. (all Plants) |

REMARKS: Plant takes water from canal and delivers it to Portal of Eagle Mountain tunnel.

Building 42' x 179'

PUMPS:

| | | | |
|---|---|---|---|
| TYPE: | Single-stage, Single-suction, Vertical | | |
| MANUFACTURER: | Worthington | | |
| SIZE DISCHARGE: | 46-1/2" | | |
| SIZE SUCTION: | 72" | | |
| RPM: | 450 | | |
| CFS: | 200 | 213.89 | 219.46 |
| HEAD: | | 440 | 447 |
| H.P. REQUIRED: | 11,300 | 12,200 | 12,650 |
| N s.: | 1400 | 1450 | 1455 |
| INSTALLED: | Jan. 1939 (units 1, 2 & 3) | | |
| HRS. OF OPERATION | Nos. 1-3 | 100,000 | |
| | 4-5 | 55,000 | |
| | 6-9 | 30,000 | |
| | (Estimated) | | |
| MIN. SUBMERGENCE: | - | | |
| NORMAL SUBMERGENCE: | - | | |
| MAX. SUBMERGENCE: | - | | |
| REMARKS: | Delivery per meters: | | |

| | | |
|---|---|---|
| No. 1 | - | 170 CFS |
| 2 | - | 165 |
| 3 | - | 205 |
| 4 | - | 216 |
| 5 | - | 220 |
| 6 | - | 195 |
| 7 | - | 216 |
| 8 | - | 204 |
| 9 | - | Down |
| Total | | 1591 |

## EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | 91.2 |
| PROTOTYPE-GUARANTEED: | - |
| PROTOTYPE-ACTUAL: | 90.0 |
| METHOD OF TEST: | - |

## CONSTRUCTION DETAILS:

| | | |
|---|---|---|
| DIAMETER DISCHARGE: | 46.5" | |
| DIAMETER IMPELLER: | - | |
| DIAMETER EYE: | 34" | |
| DIAMETER SHAFT: | 22" (Impeller bolted to flange) | |
| MATERIAL CASING: | Cast Steel | |
| MATERIAL IMPELLER: | 1-6 Bronze; | 7-9 stainless |
| MATERIAL IMPELLER RINGS: | Cast Iron | Stainless |
| MATERIAL-CASING RINGS: | CI with Brz. | Inserts - Steel |
| RADIAL CLEARANCE: | .020" - .025" | |
| MATERIAL BALANCING RINGS: | Same | |
| MATERIAL INTERSTAGE SEAL: | None | |
| RADIAL CLEARANCE: | - | |
| MATERIAL DIFFUSER: | None | |
| BEARING: | 22" x 20" | |
| THRUST BEARING: | In Motor - 33" OD. | |

| | |
|---|---|
| TYPE OF PACKING: | - |
| MATERIAL OF PACKING: | - |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical - Synchronous with direct connected exciter - 95% PF |
| MANUFACTURER: | 1-5: Westinghouse - 6-9: Elliot |
| H. P. | 12,500 |
| RPM: | 450 |
| VOLTAGE: | 6900 |
| STARTING: | Direct - full voltage |
| REMARKS: | Against closed valve. |

TURBINE:

| | |
|---|---|
| TYPE: | None |
| MFG: | - |
| HEAD: | - |
| RPM: | - |
| H. P. : | - |
| REMARKS: | - |

## VALVES:

### INTAKE:

| | |
|---|---|
| TYPE: | Butterfly |
| MANUFACTURER: | Willamette |
| SIZE: | 60" |
| OPERATION: | Motor and mechanical |

### DISCHARGE:

| | |
|---|---|
| TYPE: | Tapered Cone |
| MANUFACTURER: | 1-3: Pelton Chapman;<br>4-9: Pelton Willamette |
| SIZE: | 40-1/2 x 57 |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | 90 - 105 Seconds |
| EMERGENCY: | 75% - 3 sec.; 75% - 6 sec. |
| REMARKS: | 8" bypass with check valve. Each valve has its own accumulator. |

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Surface |
| NO. & SIZE: | Three 10' (6' branches to pumps) |
| LENGTH: | °47' |

| | |
|---|---|
| MATERIAL: | Steel (first one riveted) |
| TYPE OF UPPER GATE: | 9" x 9" sliding gate on each Penstock - 20" bypass |
| SURGE TANK: | 30' x 82' high |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Good - Clear |
| Ph: | (see analysis) |
| HARDNESS: | - |
| REMARKS: | Contains a little sand and dust acquired in the open canals. |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | - |
| STARTS/DAY: | - |
| HOURS OF OPERATION: | Nos. 1-3 100,000<br>4-5 55,000<br>6-9 30,000<br>(Estimated) |
| UNPLANNED OUTAGES: | - |
| CAUSE: | - |
| INSPECTION SCHEDULE: | - |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | - |
| TIME REQUIRED: | - |
| IMPELLER CAVITATION: | - |

| | |
|---|---|
| SEAL RING WEAR: | - |
| NOISE LEVEL-START: | - |
| NOISE LEVEL-RUN: | - |
| VIBRATION: | - |
| REMARKS: | Unit No. 5 overhauled two months ago. |

Fig. 4A-1 - View of Eagle Mountain Plant

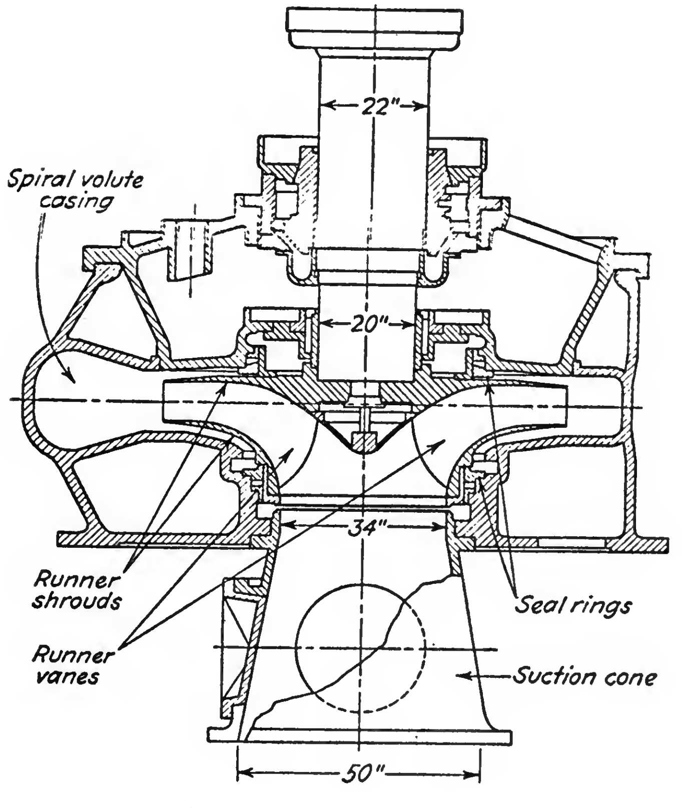



Fig. 4A - 2
Section of Pump

PLANT NAME: HAYFIELD

REPORT NO.: 5A (MWD)

| | |
|---|---|
| LOCATION-ALTITUDE: | 15 mi. West of Desert Center - 1426' |
| OWNER: | Metropolitan Water District of Southern California |
| ADDRESS: | Los Angeles |
| TYPE OF PLANT: | Surface |
| SERVICE | Pumping only - Transportation of Colorado River water to the MWD |
| TYPE OF WATER: | Clear - Lake water |
| UNITS INSTALLED: | Nine Vertical pump and motor units. |
| HORSEPOWER: | 9 x 12,500 HP (450 RPM |
| CFS: | 9 x 215 CFS |
| STATIC HEAD: | 441' |
| PLANT STARTED: | January 1939 ( 3 units) |
| VISITED BY: | Cole-Hall-Westman-Bowerman-Benz |
| DATE: | November 11, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Ralph Adams, Station Chief<br>Vern Smith, Mechanical Foreman |
| REMARKS: | Plant takes water from canal and delivers it to portal of Hayfield Tunnel.<br><br>Building 44' x 194-1/2'. |

## PUMPS:

| | |
|---|---|
| TYPE: | Vertical - Single-stage, single-suction |
| MANUFACTURER: | Worthington |
| SIZE DISCHARGE: | 40-1/2' |
| SIZE SUCTION: | 60' |
| RPM: | 450 |
| CFS: | 9 x 215 (96, 500 GPM) |
| HEAD: | 444 |
| H.P. REQUIRED: | 9 x 12, 200 |
| N s.: | 1440 |
| INSTALLED: | Jan. 1939 (3 units) |
| HRS. OF OPERATION | Nos. 1-3 100, 000<br>4-5 55, 000<br>6-9 30, 000<br>(Estimated) |
| MIN. SUBMERGENCE: | - |
| NORMAL SUBMERGENCE: | 38. 2' |
| MAX. SUBMERGENCE: | - |
| REMARKS: | Meter readings - CFS: |

| | | |
|---|---|---|
| No. 1 | - | 175 |
| 2 | - | 215 |
| 3 | - | 215 |
| 4 | - | 195 |
| 5 | - | Down |
| 6 | - | 208 |
| 7 | - | 208 |
| 8 | - | 205 |
| 9 | - | 208 |
| Total | | 1629 |

## EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | 90. 2 |
| PROTOTYPE-GUARANTEED: | - |
| PROTOTYPE-ACTUAL: | 90. 7 |
| METHOD OF TEST: | - |

## CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 40. 5" |
| DIAMETER IMPELLER: | - |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | - |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | Bronze - Stainless |
| MATERIAL IMPELLER RINGS: | - |
| MATERIAL-CASING RINGS: | - |
| RADIAL CLEARANCE: | - |
| MATERIAL BALANCING RINGS: | Same |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | None |
| BEARING: | - |
| THRUST BEARING: | In Motor |

| | |
|---|---|
| TYPE OF PACKING: | - |
| MATERIAL OF PACKING: | - |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical - Synchronous, 95% PF - direct connected exciter. Radiator cooled. |
| MANUFACTURER: | 1-5: Westinghouse; 6-9: Elliot |
| H. P. | 12, 500 |
| RPM: | 450 |
| VOLTAGE: | 6900 |
| STARTING: | Direct - full voltage |
| REMARKS: | Against closed valve (with bypass) |

TURBINE:

| | |
|---|---|
| TYPE: | None |
| MFG: | - |
| HEAD: | - |
| RPM: | - |
| H. P. : | - |
| REMARKS: | - |

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | Butterfly |
| MANUFACTURER: | - |
| SIZE: | 60" |
| OPERATION: | Electric motor or by hand. |

DISCHARGE:

| | |
|---|---|
| TYPE: | Tapered Cone |
| MANUFACTURER: | Pelton - Willamette |
| SIZE: | 40-1/2" x 57 |
| OPERATION: | |
| OPENING: | Oil Pressure |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | 60 seconds $\pm$ |
| EMERGENCY: | 90% rapid; 10% slow |
| REMARKS: | Valves have 8" bypass and check valves. |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Surface |
| NO. & SIZE: | 3 - 10' (6' branches to pumps) |
| LENGTH: | 1284' |

| | |
|---|---|
| MATERIAL: | Steel (First one rivited) |
| TYPE OF UPPER GATE: | Sliding gate |
| SURGE TANK: | Transition only |
| REMARKS: | Gates are throttled to keep plant from overriding system. |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Good - Lake water |
| Ph: | (see analysis) |
| HARDNESS: | - |
| REMARKS: | Contains some abrasive material.<br>Temperature 87° - Max.;<br>80° - Normal |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | - |
| STARTS/DAY: | - |
| HOURS OF OPERATION: | Nos. 1-3 100,000<br>4-5 55,000<br>6-9 30,000<br>(Estimated) |
| UNPLANNED OUTAGES: | - |
| CAUSE: | - |
| INSPECTION SCHEDULE: | - |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | - |
| TIME REQUIRED: | - |
| IMPELLER CAVITATION: | Yes |

| | |
|---|---|
| SEAL RING WEAR: | Some |
| NOISE LEVEL-START: | Quiet |
| NOISE LEVEL-RUN: | Quiet |
| VIBRATION: | None |
| REMARKS: | Unit No. 4 overhauled Sept. 1960 (34 days) - Wearing rings .025" - .030" out of round. Max. clearance radially .150" to .180". |

Fig. 5A-1 - View of Hayfield Pumping Plant

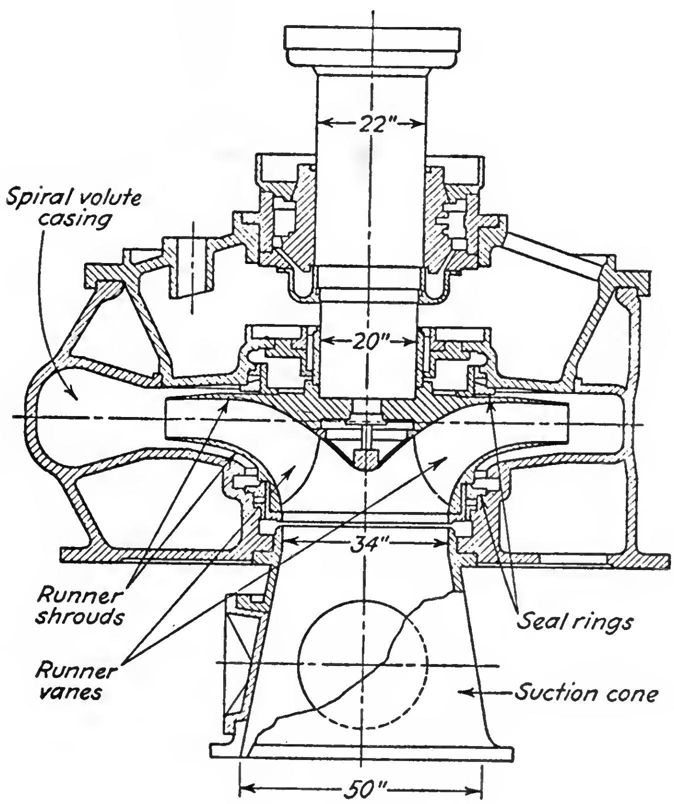



Fig. 5A-2 - Section of Pump

## GENERAL REMARKS

### Metropolitan Water District Field Trip

### November 9 - 11, 1964

The trip to the five pumping plants which comprise the pumping capacity of the Metropolitan Water District was made by Ray Hall, Glen Benz Ray Bowerman, Ray Westman, and Ernie Cole. Attached is the summary of the pump performance data collected along with noise measurements made during this inspection trip.

Five pumping plants are utilized in series along the Colorado River Aqueduct by the Metropolitan Water District for the transfer of water from Lake Havasu (Parker Dam) to Lake Mathews in the Los Angeles Basin. Each of the pumping plants is characterized by nine pumping units implemented in the period between 1937 and 1958. The performance characteristics of the Colorado River Aqueduct are such that the head required at each of the pumping stations varies. For example, the nominal head at the Intake and Gene plants is 350 feet, at Iron Mountain 146 feet, and at Eagle Mountain and Hayfield 440 feet. For capacity control, the flow rate of each of the nine pumps average 200 cubic feet per second. The particular combinations of flow rate, head, and rpm are such that the pump specific speeds range from 1400 to 2200 on a gpm basis.

It was reported to DMJM staff members that the operation of the pumps in conjunction with the Colorado River Aqueduct has been extremely simple and has required a minimum of maintenance. It must be noted, however, that during the years of operation of these pumps, the clearances at the wearing rings and seal rings have been increased to reduce the frequency of maintenance required for each of the units. This increase in seal and water ring clearance has undoubtedly reduced the efficiency of the entire system, but this reduction in efficiency is felt to be minimal when compared to reduced maintenance requirements.

Water samples were taken at Intake, Iron Mountain, Eagle Mountain, and Hayfield and silt samples at Iron Mountain and Hayfield. These samples were submitted to Truesdail Laboratory for analysis. The results are available for comparison with other pumping plant performance parameters. Since the Intake and Gene plants were adjacent, it was felt that the water at these two plants is similar. Silt was not present at Intake or Gene and not accessible at Eagle Mountain.

Noise levels were not obtained at Gene; however, the results of other noise measurements are so close that it might be assumed that the noise levels at Gene are equal to those at other plants.

Flow rates from pump to pump were seen to vary at Intake and Gene. It was stated by the operating personnel that the flow meters were accurate. The lowest and highest flow rate values at Iron Mountain, Eagle Mountain, and Hayfield were read during the inspection trip. The design flow rates at Iron Mountain are 200 cfs for units 1-6, and 224 cfs for units 7-9; these design flow rates can be compared with the observed range at Iron Mountain which was 189 to 250 cfs.

A bronze impeller was inspected that had been taken from the Hayfield plant. It had a "frosted-clean metal" appearance on all internal surfaces extending to almost the discharge area. The operating personnel called it cavitation, but damage was uniform on both vane surfaces and on the shroud surfaces of an impeller. Weld metal placed in original casting flaws stood out in relief and was not attached. Calculated suction specific speed values would indicate that Hayfield should not have an extensive cavitation problem. In fact, none of the installations have particularly high suction specific speeds. Eagle Mountain is highest, with a suction specific speed of a little over 7000.

Perhaps, a more extensive investigation into impeller surface damage at MWD plants should be undertaken.

| PARAMETERS | PUMPING PLANT | | | | |
|---|---|---|---|---|---|
| | Intake | Gene | Iron Mountain | Eagle Mountain | Hayfield |
| Head (ft.) | 294 | 310 | 146 | 440 | 444 |
| Speed (RPM) | 400 | 400 | 300 | 450 | 450 |
| Flow (CFS) | 215 (Ave) | 215 (Ave) | 189 - 250 | 200 - 219 | 192 - 208 |
| Flow (GPM) | 96,600 | 96,600 | 89,300-112,200 | 89,800-98,300 | 86,200-93,300 |
| Specific Speed | 1752 | 1690 | 2130 - 2485 | 1406 - 1470 | 1370 - 1428 |
| Forebay Elevation | | | | | |
| Normal | 446 | 735.1 | Canal 904<br>Pond 897 | Canal 966.7<br>Pond 963.5 | Entrance<br>Canal - 1366.6 |
| Range | 440 - 450 | 733.8 - 736 | | | |
| Pump Centerline | 430.0 | 712.5 | 888.0 | 944.0 | 1328.5 |
| Submergence | | | | | |
| Normal | 16 | 22.6 | C 16.0; P 9.0 | C 22.7; P 19.5 | C 38.1 |
| Range | 10 - 20 | 21.3 - 23.5 | | | |
| NPSH | | | | | |
| Normal | 47.8 | 54.4 | C 47.8; P 40.8 | C 54.5; P 51.3 | C 69.9 |
| Range | 41.8 - 51.8 | 53.1 - 55.3 | | | |
| Suction Specific Speed | | | | | |
| Normal | 6830 | 6190 | C 5550; P 6240 | C 7010; P 7390 | C 5710 |
| Range | 7590 - 6450 | 6320 - 6130 | | | |
| Noise Scale (db) | A B C | A B C | A B C | A B C | A B C |
| Motor Room | 76 81 85 | No | 76 83 89 | 79 84 88 | 75 81 85 |
| Pump Room | 84 86 87 | Readings | 84 86 88 | 84 88 91 | 84 86 88 |

MWD PUMP DATA
(Collected on Field Trip November 9-11, 1964)

## WATER ANALYSIS

The water samples were analyzed for their pH values, total alkalinity, total hardness, and total solids. These values are necessary for the calculation of the "Corrosion Index", and for the evaluation of the water samples as to their potential corrosiveness as based on their respective Corrosion Index. A positive value for the Corrosion Index signifies that the water tends to precipitate a scale of calcium carbonate which would inhibit corrosion. A negative value would indicate that the water tends to dissolve calcium carbonate and thus remove any protective barrier of this type, thus subjecting the bared metal to the corrosive action of dissolved gases in the water, such as oxygen and carbon dioxide.

The analyses of the water samples, and the calculated Corrosion Indices are as follows:

| | MWD Intake 11/9/64 | MWD Iron Mountain 11/10/64 | Eagle Mountain Res. Inlet | MWD Hayfield |
|---|---|---|---|---|
| pH | 7.96 | 7.88 | 7.98 | 7.95 |
| Total hardness (as $CaCO_3$) ppm | 332.0 | 335.6 | 333.0 | 338.4 |
| Total alkalinity (as $CaCO_3$) ppm | 117.5 | 120.0 | 70.0 | 125.0 |
| Total solids, ppm | 776 | 776 | 755 | 767 |
| Corrosion Index | +0.54 | +0.49 | +0.34 | +0.60 |

REMARKS: The above results indicate that all of the water samples would be classified as non-corrosive.

### Analysis of Silt Samples

The gravel particles were removed from the Hayfield sample prior to analysis. The silt deposits were then ground to obtain representative samples.

Treatment of the samples with hydrochloric acid indicated the presence of considerable amounts of limestone. The limestone which dissolved in the acid was separated from the insoluble silt by filtration.

The insoluble silt was examined with a microscope. It was found to be nearly entirely composed of colorless crystals of quartz. The edges of the crystalline fragments appeared to be quite sharp.

Limestone (calcite) has a hardness of 3 on the Mohs' scale, and quartz has a hardness of 7. The corresponding hardness of copper on this scale is 2.5 - 3, and of iron 4-5. We would conclude from these values that the quartz would be definitely abrasive to most metals. It will be noted in the relative amounts of limestone and quartz in the silt samples, that the Iron Mountain sample contains by far the most quartz as compared with the Hayfield sample. We would conclude from this that the Iron Mountain silt would be much more abrasive than the Hayfield silt.

| | Iron Mountain Silt | Hayfield Silt |
|---|---|---|
| Limestone, % | 25.25 | 80.44 |
| Quartz, % | 74.75 | 19.56 |

REMARKS: The particle size range of the quartz particles in the Iron Mountain silt was estimated to be 5-300 microns, and in the Hayfield silt 5-15 microns.

PLANT NAME: LEWISTON (NIAGARA FALLS)

REPORT NO.: 6A

LOCATION-ALTITUDE: One mile East of Niagara River, four miles below the Falls - 550'.

OWNER: Power Authority of the State of New York

ADDRESS: -

TYPE OF PLANT: Surface - Incorporated in the Dam

SERVICE: Pump Storage - Power generation

TYPE OF WATER: Lake water - poluted by Chemical Plants.

UNITS INSTALLED: 12 - Vertical pumping units

HORSEPOWER: 12 x 37,500 (25,000 kva as generators)

CFS: 3400

STATIC HEAD: 85' ±

PLANT STARTED: 1962

VISITED BY: Gartmann - Hall

DATE: Nov. 30, 1964

PERSON(S) INTERVIEWED & TITLE(S):
William Hilts, Head Clerk
Eugene L. Gochnauer, Supt. of Power
James B. Hamlin, Chief of Maintenance
C. L. Cummons, Chief Operator
Mr. Latham, Resident Engineer
Chas. C. Monnen, Asst. Maintenance Engineer
H. Hibbard, Asst. Chief Operator

REMARKS:

Plant pumps Niagara River water into artificial reservoir during the night off-peak, and generates power then water must be allowed to flow over the Falls.

PUMPS:

| | |
|---|---|
| TYPE: | Vertical - Single-stage, single-suction mixed flow type. |
| MANUFACTURER: | Allis-Chalmers |
| SIZE DISCHARGE: | 14' (increases to 24') |
| SIZE SUCTION: | 18' |
| RPM: | 112.5 |
| CFS: | 3400 |
| HEAD: | 85' (varies from 57' to 99') |
| H.P. REQUIRED: | 35, 200 |
| N s.: | 4950 |
| INSTALLED: | 1962 (one per month) |
| HRS. OF OPERATION | 3960 to 4200 (MWH/30)<br>Average 4062 as pump<br>Average 3615 as turbine |
| MIN. SUBMERGENCE: | -2' (to centerline of pump) |
| NORMAL SUBMERGENCE: | +2' " " " " |
| MAX. SUBMERGENCE: | +15' " " " " |
| REMARKS: | - |

## EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | 86.5% (working Moody formula backwards) |
| PROTOTYPE-GUARANTEED: | - |
| PROTOTYPE-ACTUAL: | 93% (from AC curve) |
| METHOD OF TEST: | No test - calculated from Moody with exponent of 1/4 |

## CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 14' |
| DIAMETER IMPELLER: | 206" - 180" (angle cut - 6 blades) |
| DIAMETER EYE: | 178.5" |
| DIAMETER SHAFT: | 28-1/4" (28" at bearing) |
| MATERIAL CASING: | Fabricated Steel |
| MATERIAL IMPELLER: | Steel - ASTM-A 27-25 |
| MATERIAL IMPELLER RINGS: | SAE 1020 Steel |
| MATERIAL-CASING RINGS: | SAE 1045 (Stepped) |
| RADIAL CLEARANCE: | 0.100" |
| MATERIAL BALANCING RINGS: | (balanced through holes in hub) |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | 20 adjustable cast steel wickets |
| BEARING: | 28" dia. - 21-5/8 long - Babbitt lined. |
| THRUST BEARING: | In motor (Weight of rotating element - - 157.5 tons) |

| | |
|---|---|
| TYPE OF PACKING: | Adjustable |
| MATERIAL OF PACKING: | Soft packing |
| MATERIAL OF SLEEVE: | Stainless steel |
| CLEARANCE: | None |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical Synchronous - D. C. Exciter |
| MANUFACTURER: | 6 - Allis-Chalmers<br>6 - S. Morgan Smith |
| H. P. | 37,500 |
| RPM: | 112.5 |
| VOLTAGE: | 13,200 |
| STARTING: | Direct Full Voltage |

REMARKS: Unwatered pump - wickets closed. Comes up to speed in 12 seconds. Starting power exceeds 75,000 kva for several seconds (25,000-30,000 Amps.)

TURBINE:

| | |
|---|---|
| TYPE: | (Reverse Pump) |
| MFG: | Allis-Chalmers |
| HEAD: | 75' |
| RPM: | 112.5 |
| H. P.: | 28,000 |
| REMARKS: | - |

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | Sliding Gate |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | - |

DISCHARGE:

| | |
|---|---|
| TYPE: | Sliding Gate at top of Penstock |
| MANUFACTURER: | - |
| SIZE: | 24' x 24' |
| OPERATION: | |
| OPENING: | Gantry Crane |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | 60% in 12.8 seconds |
| REMARKS: | - |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Through Dam |
| NO. & SIZE: | One for each Pump - 14' increasing to 24' square. |
| LENGTH: | Very short - approximately 210' |

| | |
|---|---|
| MATERIAL: | Enclosed in concrete |
| TYPE OF UPPER GATE: | Sliding - 24' x 24' |
| SURGE TANK: | None |
| REMARKS: | Drain Penstock to service pump. |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Clear lake water |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | Somewhat poluted by effluent from chemical plants. |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | Daily |
| STARTS/DAY: | Approximately two. |
| HOURS OF OPERATION: | Pump - 3960-4200 (Avg. 4062)<br>Turbine 3400-3850 (Avg. 3615) |
| UNPLANNED OUTAGES: | None due to pump or motor. |
| CAUSE: | Mostly electrical controls. |
| INSPECTION SCHEDULE: | None between overhauls. |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | Once each year |
| TIME REQUIRED: | About 12 days |
| IMPELLER CAVITATION: | Yes |

| | |
|---|---|
| SEAL RING WEAR: | A little |
| NOISE LEVEL-START: | - |
| NOISE LEVEL-RUN: | A- 95; B- 100; C- 103 (as turbine) |
| VIBRATION: | - |
| REMARKS: | Pumps inspected each year. Repairs consist of overlaying cavitation spots on blades with stainless steel, and inspecting for ring wear.<br><br>Impeller seal rings, originally shrunk on, have loosened on two pumps. Corrected by spot welding ring to impeller. |

## GENERAL REMARKS

The Lewiston Pump Generating plant, like the St. Lawrence Project, is a venture of the New York State Power Authority. The redevelopment of the Niagara Falls was made possible by the Treaty of 1950 between the United States and Canada, whereby the amount of water flowing over the Falls, to maintain its scenic value, must not be less than 100, 000 cfs during the daylight hours from April through October. Nor may it be less than 50, 000 cfs the remainder of the time. The substantial amounts of additional flow are divided equally between the two countries.

Unfortunately the additional 50, 000 cfs of water available during the night hours seven months of the year occurs during a period of low demand for electricity. However, by means of the Lewiston pumped-storage project, off-peak power at night can be utilized advantageously to drive the units as pumps. Excess water is thereby stored in a large man-made reservoir. During peak power demand periods, water from the storage reservoir is then utilized to drive the units in the reverse direction to generate power and further increase the water supply available to the Robert Moses Niagara Power Plant.

Each of the twelve Lewiston Pump Generating units, as a 37, 500 hp motor-driven pump, is designed to deliver 3400 cfs of water to the storage reservoir against a total dynamic head of 85 feet, but which will vary from 57 to 99 feet. In reverse rotation, as a turbine driven generator each is rated 28, 000 hp under a 75 ft. head to generate 25, 000 kva at . 8% P. F. The turbine net head will vary from 53 to 95 ft. The units operate at 112. 5 rpm.

Six of the runners are solid steel castings. The other seven, including the spare runner, are of fabricated construction with cast steel buckets welded to the steel crowns and discharge bands. The lower portion of the buckets are stainless steel.

Prior to construction, a homologus model of these pump-turbines was tested for performance and cavitation characteristics in the company's hydraulic laboratory.

Fig. 6A-1 - Aerial view of plant location, looking south from above the Niagara River. Niagara Falls at left and Lewiston Plant and Reservoir at upper right.

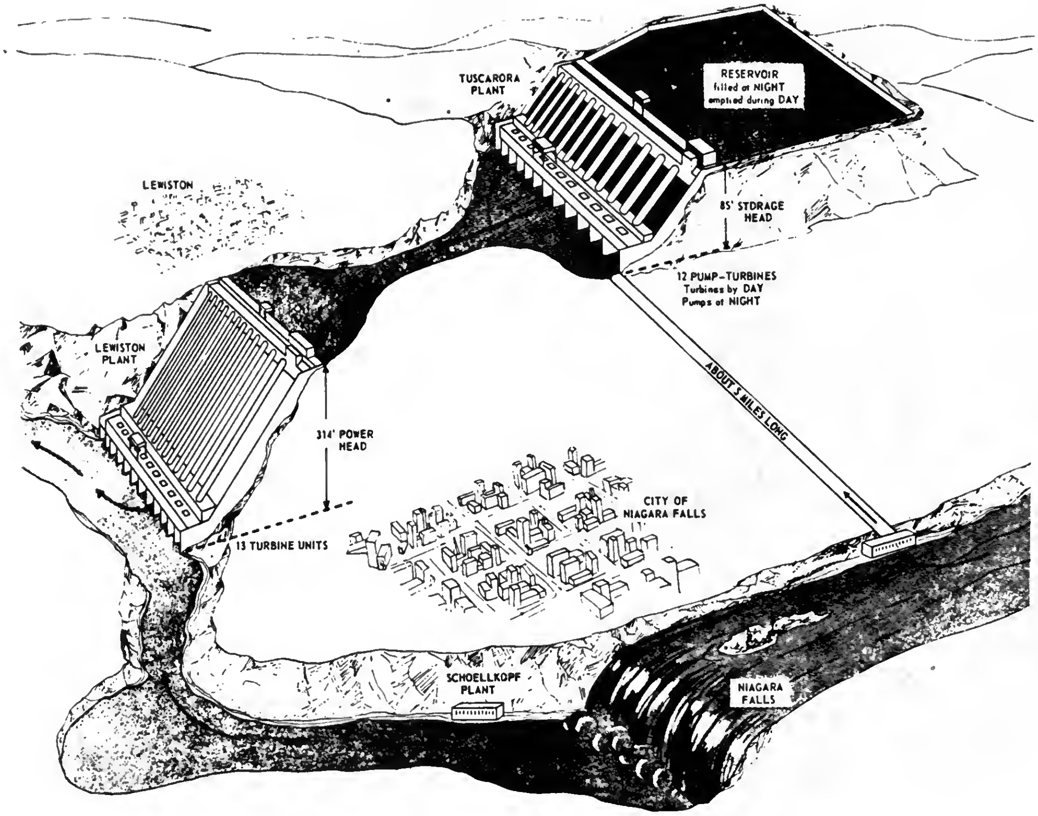



Fig. 6A-2 - Artists Sketch of System

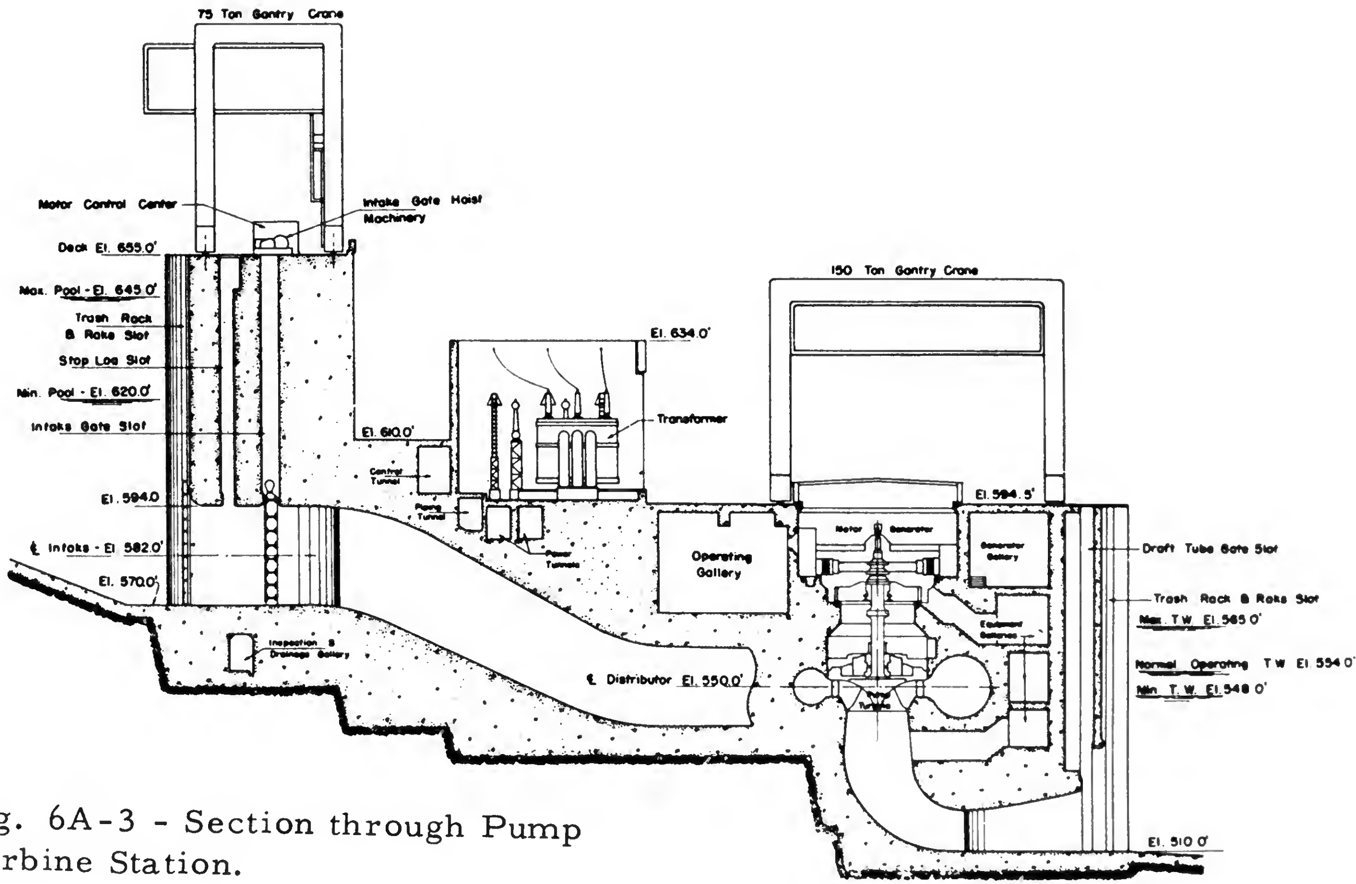



Fig. 6A-3 - Section through Pump Turbine Station.

PLANT NAME: HIWASSEE

REPORT NO.: 7A

| | |
|---|---|
| LOCATION-ALTITUDE: | Western North Carolina - 1271' |
| OWNER: | Tennessee Valley Authority |
| ADDRESS: | Edney Bldg. - Chattanooga, Tennessee |
| TYPE OF PLANT: | Surface - Incorporated in Dam |
| SERVICE | Pump storage and power generation for TVA System. |
| TYPE OF WATER: | Good - Lake water |
| UNITS INSTALLED: | One single-stage, vertical pump-turbine unit. |
| HORSEPOWER: | 102,000 (70,000 kva as Generator) |
| CFS: | 3900 |
| STATIC HEAD: | 205 |
| PLANT STARTED: | May, 1956 |
| VISITED BY: | Gartmann - Hall |
| DATE: | December 1, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | T. F. Faulkner, Asst. Elect. Supt. (Chat.)<br>R. C. Price, Plant Supervisor, Elect. "<br>W. B. Floyd, Asst. Supt. (Plant)<br>Mr. Williams, Sr. Operator (Plant) |

REMARKS: Plant mostly for power generation. Returns water to Hiwassee Lake during periods of drouth. Unit runs continuously as pump, generator or condenser.

PUMPS:

| | |
|---|---|
| TYPE: | Vertical - Single-stage, single-suction |
| MANUFACTURER: | Allis-Chalmers |
| SIZE DISCHARGE: | 16 ft. |
| SIZE SUCTION: | 194" |
| RPM: | 105.9 |
| CFS: | 3900 |
| HEAD: | 205 (135 to 254) |
| H.P. REQUIRED: | 100,000 |
| N s.: | 2590 |
| INSTALLED: | May 1956 |
| HRS. OF OPERATION | Pump - 44.7<br>Turbine - 6029 |
| MIN. SUBMERGENCE: | 3' (To center line of Runner) |
| NORMAL SUBMERGENCE: | 9' " " " " " |
| MAX. SUBMERGENCE: | 49' |
| REMARKS: | Single pump installed. There has been ample rainfall, so unit not operated as a pump. |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | 90% |
| PROTOTYPE-GUARANTEED: | 90% at 3900 cfs |
| PROTOTYPE-ACTUAL: | 907.7% (91.4-91.7 as a turbine) |
| METHOD OF TEST: | Salt velocity - Also reservoir level change - metered. |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 16' (increasing to 18') |
| DIAMETER IMPELLER: | 267-5/8" |
| DIAMETER EYE: | 182" |
| DIAMETER SHAFT: | 40" |
| MATERIAL CASING: | Fabricated Steel |
| MATERIAL IMPELLER: | ASTM - A 27-60T Grade 70.36 annealed. |
| MATERIAL IMPELLER RINGS: | SAE - 1045 |
| MATERIAL-CASING RINGS: | SAE - 1025 |
| RADIAL CLEARANCE: | .100" |
| MATERIAL BALANCING RINGS: | Same |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | Vanes - Steel |
| BEARING: | 40-1/4" x 30" |
| THRUST BEARING: | Kingsbury - 84" dia. |

| | |
|---|---|
| TYPE OF PACKING: | Adjustable |
| MATERIAL OF PACKING: | Graphite - Type 430 |
| MATERIAL OF SLEEVE: | Chrome Steel |
| CLEARANCE: | None |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical Synchronouse - direct connected Exciter - Semi outdoors units |
| MANUFACTURER: | Allis-Chalmers |
| H. P. | 102,000 HP (70 000 kva) |
| RPM: | 105.9 |
| VOLTAGE: | 13,800 |
| STARTING: | 50% reduced voltage - dewatered pump |
| REMARKS: | - |

TURBINE:

| | | |
|---|---|---|
| TYPE: | (Pump in reverse) | |
| MFG: | Allis-Chalmers | |
| HEAD: | 190' | 254.5' |
| RPM: | 105.9 | |
| H. P.: | 80,000 | 120,000 |
| REMARKS: | - | |

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | Stop Gates |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | - |

DISCHARGE:

| | |
|---|---|
| TYPE: | Stop Gate at top of Penstock |
| MANUFACTURER: | - |
| SIZE: | 19' wide x 26' high |
| OPERATION: | |
| OPENING: | Hoists in Dam |
| CLOSING: | - |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | - |

PENSTOCK:

| | |
|---|---|
| SURFACE OR U. G. | Through Dam |
| NO. & SIZE: | One |
| LENGTH: | Short |

| | |
|---|---|
| MATERIAL: | - |
| TYPE OF UPPER GATE: | Sliding Gate |
| SURGE TANK: | None |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Good clean Lake water |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | Quality unknown |

<u>MAINTENANCE AND OPERATION:</u>

| | |
|---|---|
| OPERATING SCHEDULE: | Runs continuously as pump, generator, or condenser |
| STARTS/DAY: | Started only 4 or 5 times as pump |
| HOURS OF OPERATION: | Pump - 44.7 hours<br>Turbine - 6029 hours |
| UNPLANNED OUTAGES: | - |
| CAUSE: | - |
| INSPECTION SCHEDULE: | Once per year, 1st three years, now every 2 - 3 years. |
| TIME REQUIRED: | 5 men - 5 dams |
| OVERHAUL SCHEDULE: | None to date |
| TIME REQUIRED: | " " |
| IMPELLER CAVITATION: | Apparently None |

| | |
|---|---|
| SEAL RING WEAR: | Practically none |
| NOISE LEVEL-START: | - |
| NOISE LEVEL-RUN: | A- 82; B- 90; C- 94 (78% Gate opening) |
| VIBRATION: | None |
| REMARKS: | Not enough operation as a pump to draw any conclusions. |

## GENERAL REMARKS

One of the world's largest electric motors and reversible pump-turbines was placed in service in southwestern North Carolina in May, 1956. The unit is the heart of a pump-storage project at Hiwassee Dam on TVA's power network. In this installation, a single reversible pump-turbine operates in one direction as a turbine and in the reverse direction as a pump. A direct-connected generator-motor serves as a motor for pump operation and as a generator for turbine operation. Speed is 105.9 rpm in either direction.

Water from Hiwassee Reservoir drives the unit as a turbine-generator, adding needed energy to the TVA system in peak demand periods. During off-peak periods, when surplus power is available from other plants, the unit operates as a motor-driven pump to lift water back into the reservoir.

The unit utilizes the largest Francis impeller runner ever built. The generator-motor as a motor is rated 102,000 hp. As a generator, it is rated 70,000 kva at 13,800 volts.

In a normal cycle of operation, the pump begins lifting water from Apalachia Lake into Hiwassee Lake under a head of 170 feet at about 4600 cubic feet per second. By the time the upper reservoir is filled, the head increases to 254.5 feet. The rated pumping capacity is 3900 cubic feet per second against a 205 ft. head.

Operating as a turbine it is rated 80,000 hp at 190 ft. head. Under the higher heads, the unit can generate 120,000 hp, and as much as 48,000 hp under the lowest head. Guaranteed efficiencies were 90% as a pump and 89.5% as a turbine.

Fig. 7A-1 - View of Dam and Power House

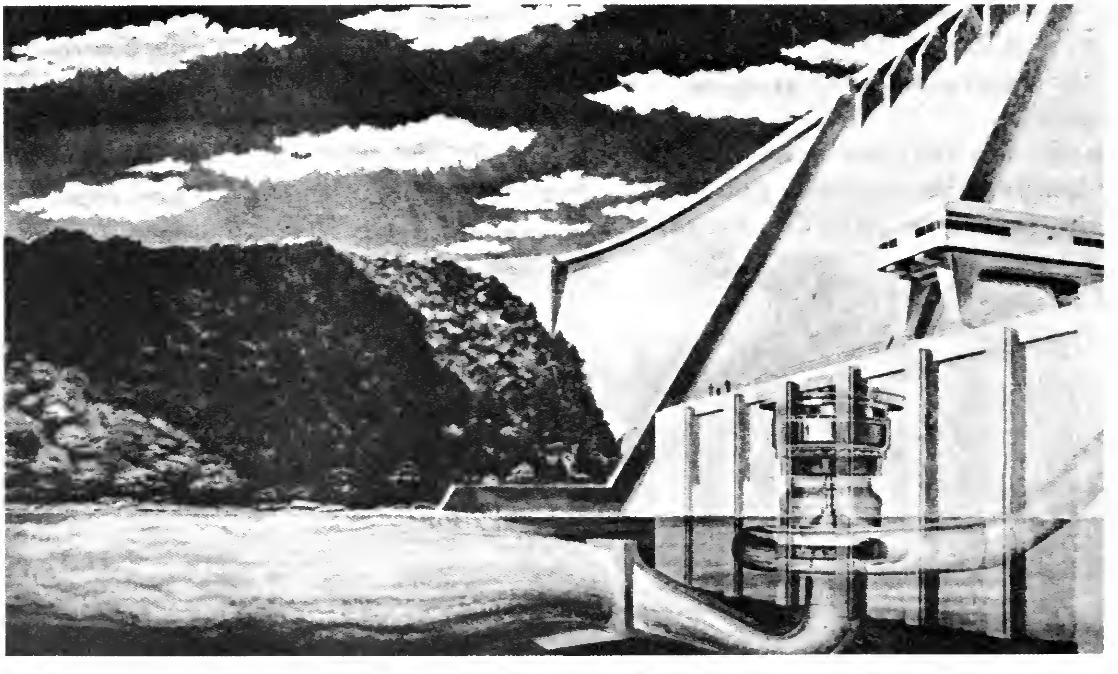


Fig. 7A-2 - Phantom Sketch of Pump Turbine installation.

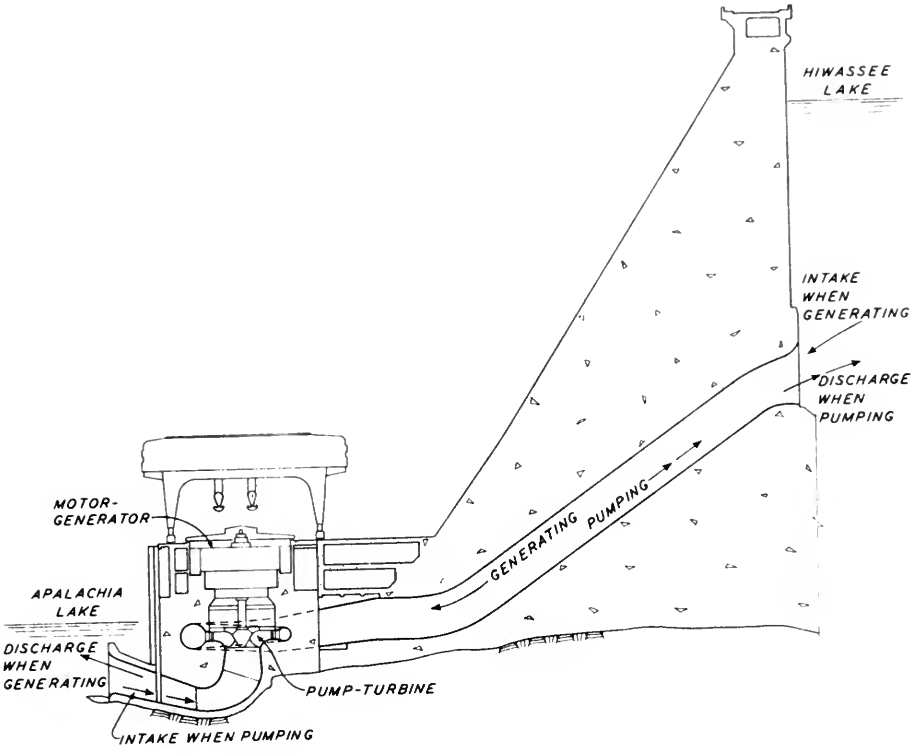



Fig. 7A-3 - Section through Dam

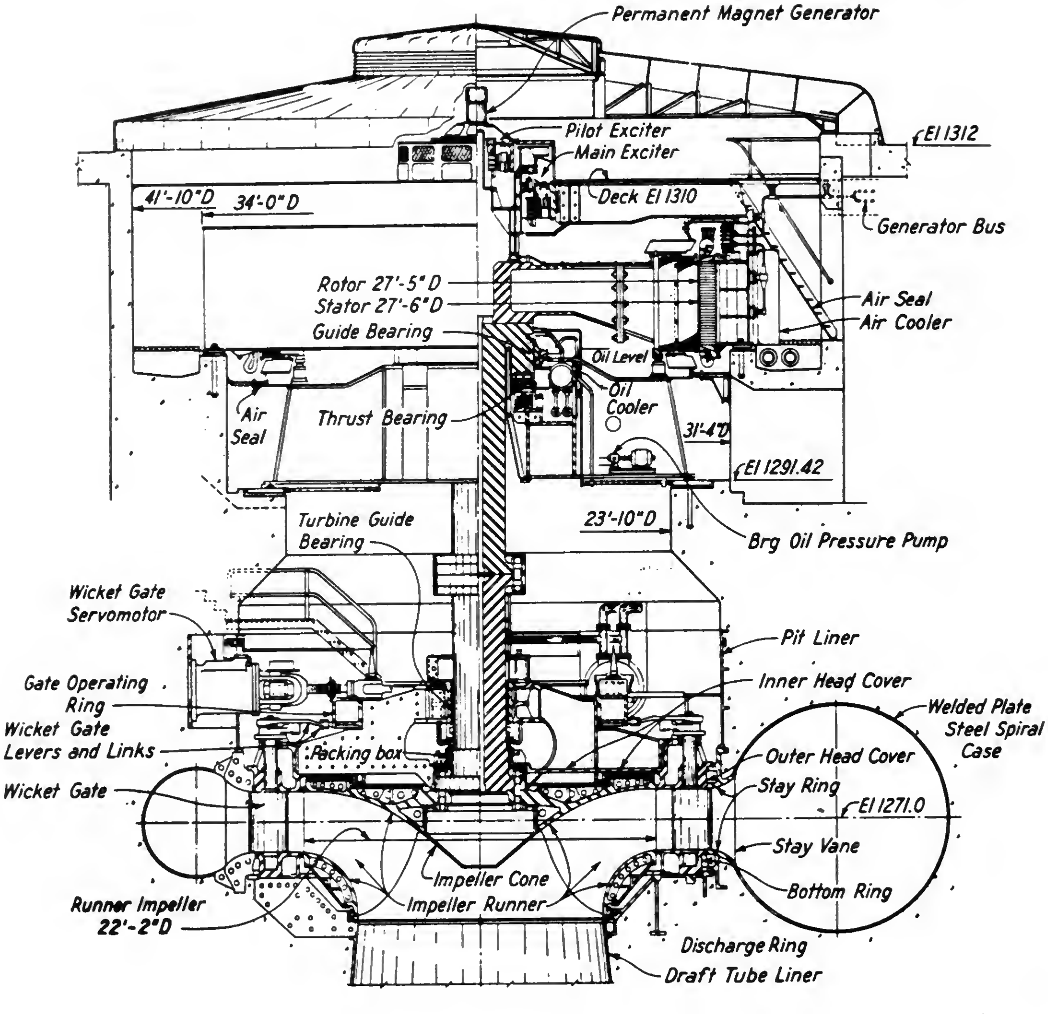



Fig. 7A-4 - Section through Pump - Turbine Unit

PLANT NAME: TRACY

REPORT NO.: 8 A

| | |
|---|---|
| LOCATION-ALTITUDE: | Tracy, California - Sea Level |
| OWNER: | U.S.B.R. |
| ADDRESS: | Denver, Colorado |
| TYPE OF PLANT: | Pumping |
| SERVICE | Irrigation |
| TYPE OF WATER: | River water, shallow muddy channel |
| UNITS INSTALLED: | Six (6) |
| HORSEPOWER: | 22,500 (180 RPM) |
| CFS: | 850 |
| STATIC HEAD: | 197 |
| PLANT STARTED: | July 1951 |
| VISITED BY: | G. Benz - R. Bowerman |
| DATE: | Dec. 2, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Mr. Lyons, Chief Operator<br>Mr. Winchester, Maintenance |
| REMARKS: | Six units raise Delta water in Delta Mendota Canal from sea level to approximately 197'. Plant semi-outdoors type 362' x 59' |

PUMPS:

| | | |
|---|---|---|
| TYPE: | 1st stage, single suction | |
| MANUFACTURER: | Worthington | |
| SIZE DISCHARGE: | 84" (increased to 108") | |
| SIZE SUCTION: | 6.4 ft. | |
| RPM: | 180 | |
| CFS: | 850 | 767 |
| HEAD: | 197 | 197 |
| H.P. REQUIRED: | 21,300 | 19,200 |
| N s.: | 2110 | 2000 |
| INSTALLED: | July 1951 | |
| HRS. OF OPERATION | 35,000 on each of six pumps | |
| MIN. SUBMERGENCE: | Minus one ft. | |
| NORMAL SUBMERGENCE: | Four ft. | |
| MAX. SUBMERGENCE: | Ten ft. | |
| REMARKS: | - | |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | Unknown |
| MODEL ACTUAL: | Unknown |
| PROTOTYPE - GUARANTEED: | 88 - (89.3 predicted from model test) |
| PROTOTYPE-ACTUAL: | 91.6 |
| METHOD OF TEST: | Salt Velocity |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 84 |
| DIAMETER IMPELLER: | 12 ft. |
| DIAMETER EYE: | 6.4 ft. |
| DIAMETER SHAFT: | 1.7 ft. |
| MATERIAL CASING: | Cast Iron |
| MATERIAL IMPELLER: | Manganese Bronze |
| MATERIAL IMPELLER RINGS: | Manganese Bronze, now stainless |
| MATERIAL-CASING RINGS: | Manganese Bronze, now stainless |
| RADIAL CLEARANCE: | 0.035" - .040" |
| MATERIAL BALANCING RINGS: | Manganese Bronze, now stainless steel |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | None |
| BEARING: | - |
| THRUST BEARING: | Kingsbury |

| | |
|---|---|
| TYPE OF PACKING: | Adjustable stuffing box |
| MATERIAL OF PACKING: | "Garlock" square, graphite impreg. |
| MATERIAL OF SLEEVE: | Bronze |
| CLEARANCE: | None |
| REMARKS: | Packing unsatisfactory, lasts only about a year. Grease increases life but causes trouble if pump runs backward, so don't use. |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical - Synchronous - Direct connected exciter. |
| MANUFACTURER: | Allis-Chalmers |
| H.P.: | 22,500 |
| R.P.M.: | 180 |
| VOLTAGE: | 13,600 |
| STARTING: | Across-the-line against closed discharge. |
| REMARKS: | $WR^2$ = 3,500,000 LB - $FT^2$. Seal water provided for running dewatered pump as synchronous condenser. |

TURBINE:

| | |
|---|---|
| TYPE: | None |
| MFG.: | - |
| HEAD: | - |
| R.P.M.: | - |
| H.P.: | - |
| REMARKS: | - |

VALVES:

| | |
|---|---|
| INTAKE: | Bulkhead Gates |
| TYPE: | Structural Steel |
| MANUFACTURER: | - |
| SIZE: | 13' x 12' (two for each pump) |
| OPERATION: | Raised by 100 ton Gantry crane. |

| | |
|---|---|
| DISCHARGE: | |
| TYPE: | Butterfly |
| MANUFACTURER: | Newport News Shipbuilding |
| SIZE: | 108" |
| OPERATION: | |
| OPENING: | Oil and Air Pressure of 400 PSI |
| CLOSING: | " " " " " |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | - |

PENSTOCK:

| | | |
|---|---|---|
| SURFACE OR U. G. | Underground, covered with fill | |
| NO. & SIZE: | 6, 12' Ø to | 3, 15' Ø |
| LENGTH: | 130' | 800' |

| | |
|---|---|
| MATERIAL: | Pre cast - Concrete |
| TYPE OF UPPER GATE: | Syphon with vent and relief valve |
| SURGE TANK: | - |
| REMARKS: | Syphon breakers |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Much fine silt when pumping. Turbidity 18-53 |
| Ph: | About 7 |
| HARDNESS: | - |
| REMARKS: | Sample to be analyzed |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | All year except Winter |
| STARTS/DAY: | 20 starts/1000 hrs. operation |
| HOURS OF OPERATION: | 35,000 on ea. of six pumps |
| UNPLANNED OUTAGES: | None for pumps |
| CAUSE: | Spare pump capacity |
| INSPECTION SCHEDULE: | Yearly |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | About every ten years |
| TIME REQUIRED: | About two months |
| IMPELLER CAVITATION: | Little |

| | |
|---|---|
| SEAL RING WEAR: | .034" to .080 increase upper - .074" to .112" increase lower. |
| NOISE LEVEL-START: | - |
| NOISE LEVEL-RUN: | A- 82; B- 86; C- 88 |
| VIBRATION: | - |
| REMARKS: | No pumps running during visit. Impellers developed cracks after year or two operation. Repaired by Worthington using chain lock method and okey since.<br><br>Motor poles had to be rebuilt because they were overheating. Dampener bars loosened at end rings. |

## GENERAL REMARKS

The Tracy pumping plant is one of the key elements of the USBR Central Valley Project. Waters accumulating in the Delta region from the Sacramento, American and Trinity Rivers are pumped by the six (6) Tracy pumps through the Delta-Mendota canal, a distance of 117 miles to the south. Irrigation water is supplied to lands en route and the remaining flow replaces normal San Joaquin River flow that is now stored by the Friant Dam on the other side of the San Joaquin Valley.

Power for the pumps is developed at Shasta, Keswick, Folsom, Nimbus, and Trinity power plants. Adjacent to the pumping plant is the Tracy Switchyard, which is the southerly terminus for the Central Valley Project power transmission system.

In developing the pumps, the Worthington Company constructed a scale model pump, including an inlet section and discharge butterfly valve and the model was tested as a unit. The model scale was 9.6 to 1. Eight different impellers were tested before the final design was selected. Results of the tests were:

At 197 ft. load;

| | |
|---|---|
| Required: | $Q \geq 757$ cfs Eff $\geq 88.0$ |
| Predicted from Model Curves | $Q = 785$ cfs Eff - 89.3 |
| Field tests on one pump | $Q = 850$ cfs* Eff = 91.6 |

* by salt velocity method

The pump cases are fabricated from high strength grey iron. Impellers are "turbine runner" bronze.

The plant has been operating since 1951 and runs continuously, except for the Winter season. Water demands change during the year, and so the number of pumps running at any one time is variable. There is a one-pump spare capacity. All six (6) pumps have accumulated over 35,000 hrs. each. Impellers show very little cavitation erosion, and it is localized at the vane shroud intersection. Cracks in impeller castings that occured in the early period of operation were satisfactorily repaired by Worthington Corp., using "chain lock" inserts.

Pump motors (22, 500 HP rating each) are normally started across-the-line, with the discharge valve closed. Provision was made for operating pumps dewatered, so that units could function as synchronous condensers for the switchyard, but this operation is rarely used.

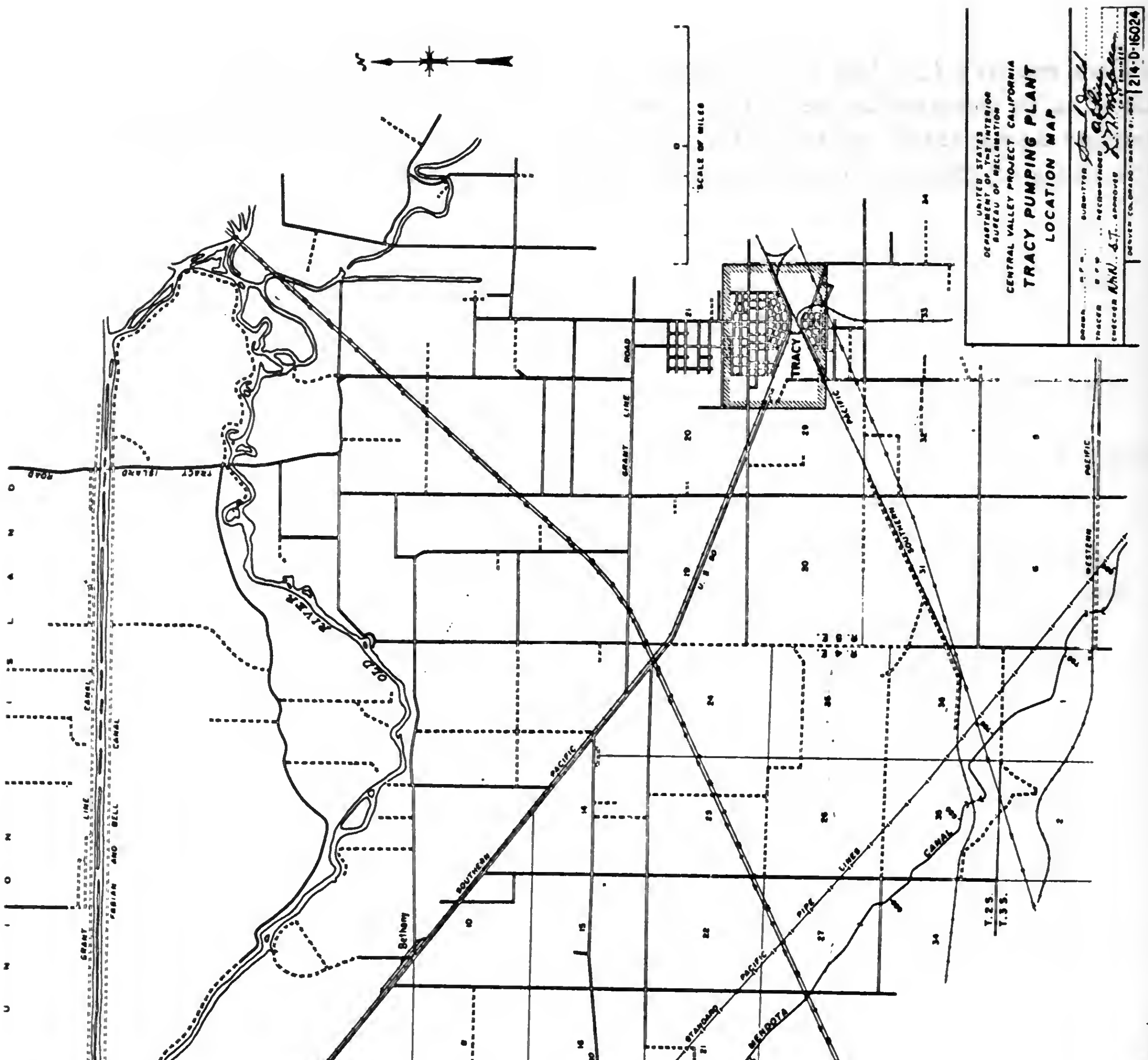



Fig. 8A-1 - Location of Tracy Plant

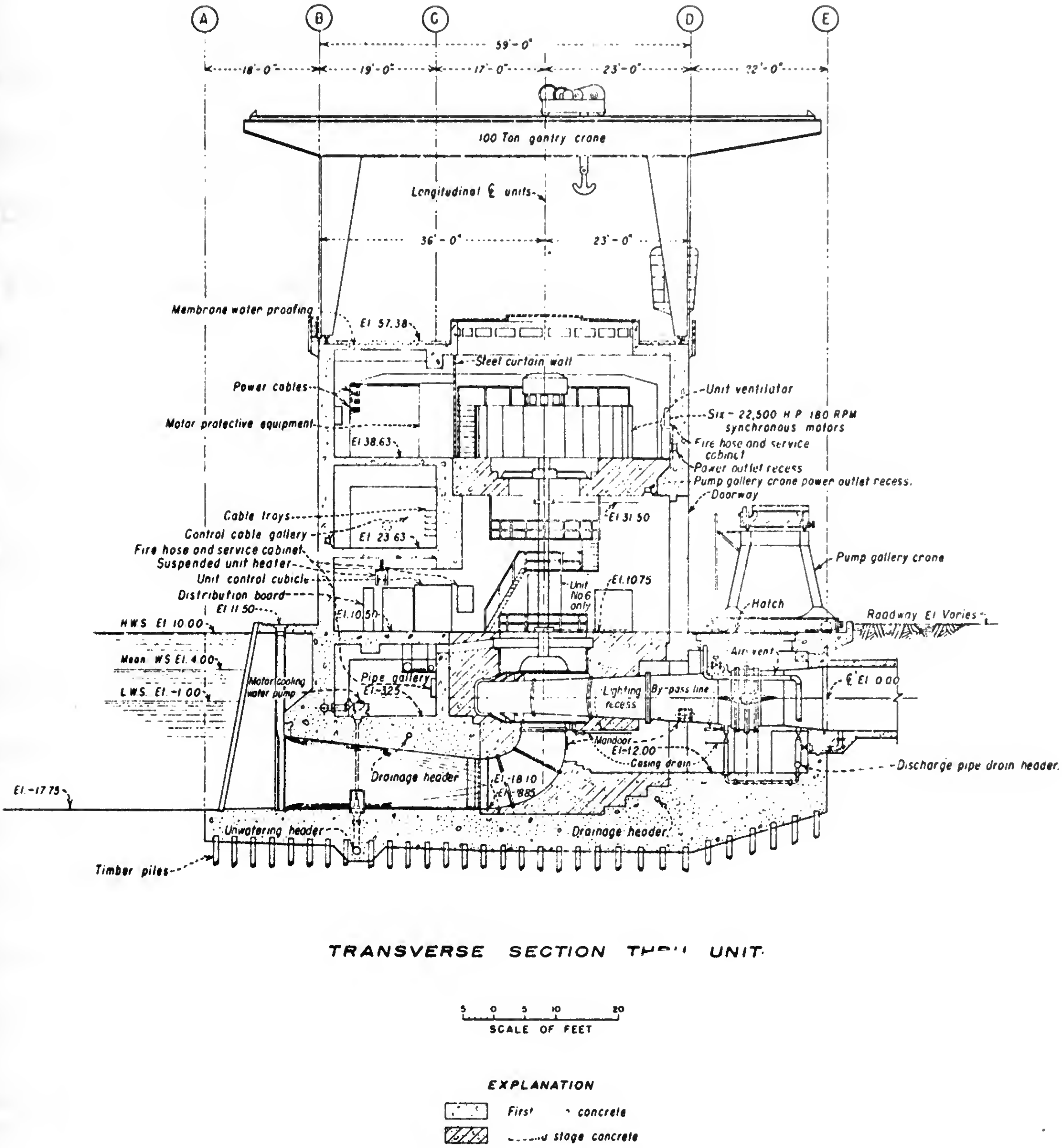



Fig. 8A-2 - Tracy Pumping Plant - transverse section through a pump unit.

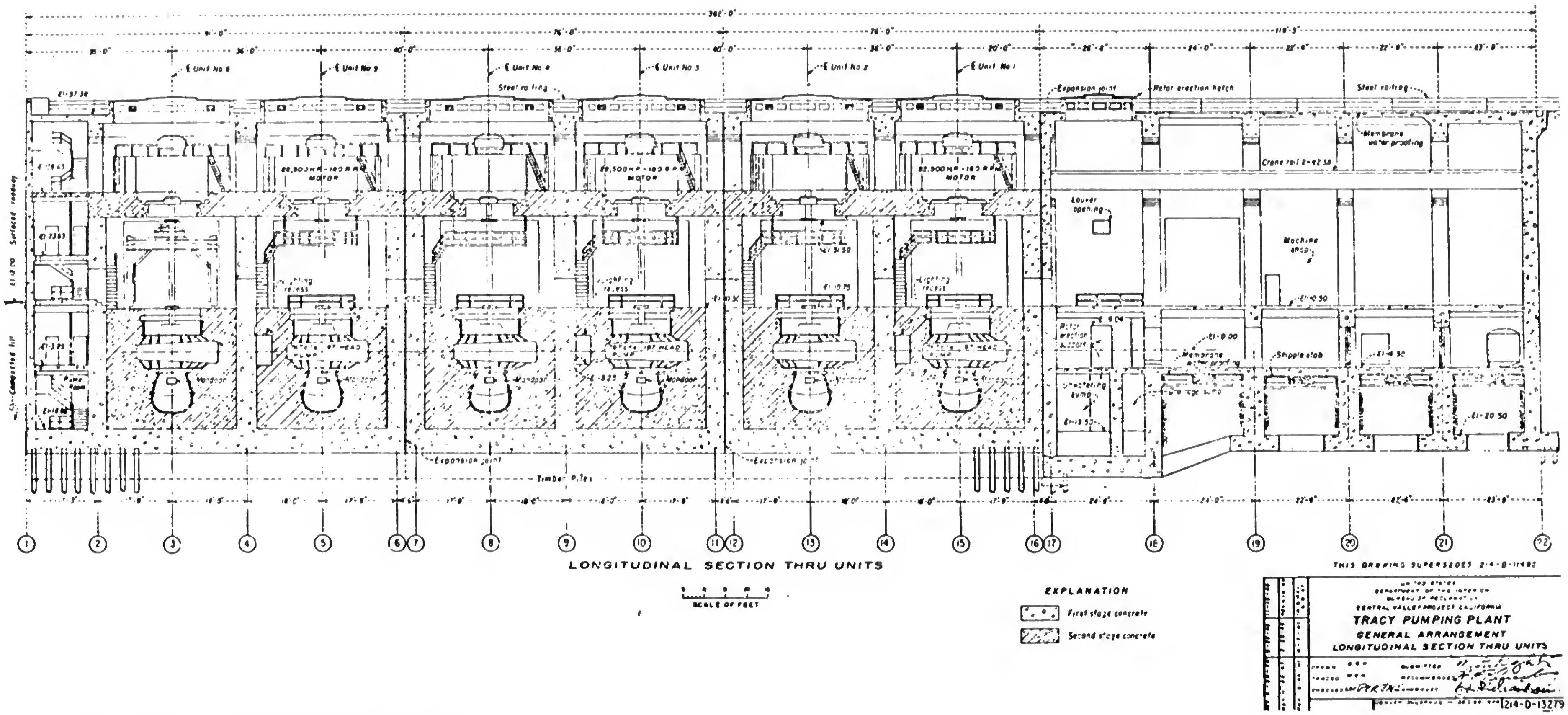



Fig. 8A-3 - Longitudinal Section

PLANT NAME: GRAND COULEE

REPORT NO.: 9A

| | |
|---|---|
| LOCATION-ALTITUDE: | 86 miles West of Spokane - 1203' |
| OWNER: | Bureau of Reclamation |
| ADDRESS: | Ephrata, Washington |
| TYPE OF PLANT: | Pumping - Surface |
| SERVICE | Irrigation - Raises water from Lake Roosevelt to feeder canal |
| TYPE OF WATER: | Clear |
| UNITS INSTALLED: | Six (6) single-stage, single-suction vertical, motor-driven pumps |
| HORSEPOWER: | 6 x 65,000 (200 RPM) |
| CFS: | 6 x 1310 |
| STATIC HEAD: | 275.50 to 357.50' |
| PLANT STARTED: | 1951 - 1952 |
| VISITED BY: | Hall - Gartmann |
| DATE: | Nov. 24, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Glen R. Barker, Supervisory Elec. Engineer<br>Jim Minor, Mechanical Engineer |
| REMARKS: | Six (6) pumps installed. Plant designed for twelve (12) pumps. Pumps operated in Spring and Summer only. |

PUMPS:

| | | | | | | |
|---|---|---|---|---|---|---|
| TYPE: | Vertical, Single-stage, single-suction | | | | | |
| MANUFACTURER: | Byron Jackson | | | | | |
| SIZE DISCHARGE: | 12 ft. | | | | | |
| SIZE SUCTION: | 14 ft. | | | | | |
| RPM: | 200 | | | | | |
| CFS: | 1350 | 1600 | | | | |
| HEAD: | 311 | 280 | | | | |
| H.P. REQUIRED. | 51,000 | 61,200 | | | | |
| N s.: | 2100 | 2490 | | | | |
| INSTALLED: | 1951 & 1952 | | | | | |
| HRS. OF OPERATION Nos. | 1 | 2 | 3 | 4 | 5 | 6 |
| | 18,800 | 21,800 | 21,400 | 21,100 | 20,000 | 17,900 |
| MIN. SUBMERGENCE: | To center line of impeller | 7'-(min. experienced '57) | | | | |
| NORMAL SUBMERGENCE: | | 77' | | | | |
| MAX. SUBMERGENCE: | | 87' | | | | |
| REMARKS: | - | | | | | |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | 87% |
| MODEL ACTUAL: | 90% |
| PROTOTYPE-GUARANTEED: | 87% |
| PROTOTYPE-ACTUAL: | 93. 9 (max.) |
| METHOD OF TEST: | Salt velocity |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 12 ft. |
| DIAMETER IMPELLER: | 167-3/8" |
| DIAMETER EYE: | 89-3/8" |
| DIAMETER SHAFT: | 28" |
| MATERIAL CASING: | Fabricated steel |
| MATERIAL IMPELLER: | Steel |
| MATERIAL IMPELLER RINGS: | Bronze |
| MATERIAL-CASING RINGS: | Bronze |
| RADIAL CLEARANCE: | .035 (now 0. 100") |
| MATERIAL BALANCING RINGS: | Same |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | None |
| BEARING: | 27-1/4 x 27" Babbitt (.012" C/L) |
| THRUST BEARING: | In motor - Spring loaded. |

VALVES:

INTAKE:

| | |
|---|---|
| TYPE: | Reverse flow coaster gate |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | - |

DISCHARGE:

| | |
|---|---|
| TYPE: | None |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | |
| OPENING: | - |
| CLOSING: | - |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | - |

PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Lower 3/4 UG - upper 1/4 surface |
| NO. & SIZE: | 6 x 12' |
| LENGTH: | 850' |

| | |
|---|---|
| TYPE OF PACKING: | Adjustable |
| MATERIAL OF PACKING: | Teflon - Asbestos |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | None |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical Synchronous - MG set for excitation. |
| MANUFACTURER: | Four (4) Westinghouse<br>Two (2) General Electric |
| H. P. | 65,000 |
| RPM: | 200 |
| VOLTAGE: | 13,800 |
| STARTING: | Against empty penstock - No valve |
| REMARKS: | Turbine slowed down to 1/2 speed. Motor locked in electrically. Speed drops to 1/4 speed. Motor and turbine brought up to speed in 10 minutes. |

TURBINE: (In separate plant - 18 units)

| | |
|---|---|
| TYPE: | Francis |
| MFG: | Newport News Shipbuilding and D. D. Co. |
| HEAD: | 345' |
| RPM: | 120 |
| H. P.: | 150,000 (108,000 kw) |
| REMARKS: | - |

| | |
|---|---|
| MATERIAL: | Steel |
| TYPE OF UPPER GATE: | None |
| SURGE TANK: | None |
| REMARKS: | Syphon and 30" Syphon Breaker at top. |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Clear water from Lake Roosevelt |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | - |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | From May 1st until into Sept. - 24 hours per day |
| STARTS/DAY: | 1 to 5 per month |

| HOURS OF OPERATION: No. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Approx: | 18,800 | 21,800 | 21,400 | 21,100 | 20,000 | 17,900 |
| UNPLANNED OUTAGES: | 6 | 6 | 5 | 5 | 3 | 2 |

| | |
|---|---|
| CAUSE: | See Below |
| INSPECTION SCHEDULE: | Once per week |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | None |
| TIME REQUIRED: | - |
| IMPELLER CAVITATION: | Yes (See below) |

| | |
|---|---|
| SEAL RING WEAR: | Some |
| NOISE LEVEL-START: | - |
| NOISE LEVEL-RUN: | - |
| VIBRATION: | - |
| REMARKS: | Cavitation on both sides of blades. Repaired by stainless E-308 and E-309 welding, after 6000 hours of operation.<br><br>Wear on both impeller shrouds. Only one impeller removed for balance.<br><br>Some corrosion. Packing trouble prevalent. Exciter trouble.<br><br>A few outages, due to station piping and oil coolers. |

## GENERAL REMARKS

The pumping plant is situated at the Grand Coulee Dam on the Columbia River in the State of Washington. This huge pumping plant consists of six vertical single-stage pumping units. Each unit is driven by a 65,000 HP motor, or a total of 780,000 HP for the complete pumping plant. The pumps have a wide operating head range, from 365 to 270 ft., with a corresponding capacity of 1100 cfs to 1650 cfs, when operating at the constant speed of 200 rpm. The pumps are of the vertical single-stage single-suction type, with 12 ft. diam. discharge and a 14 ft. diam. suction.

In order to obtain strict and exacting final specifications, a research program lasting 2-1/2 years was conducted at the Hydraulic Machinery Laboratory of the California Institute of Technology (later called Cal Tech), sponsored by the Bureau of Reclamation, and carried through with the cooperation of three pump manufacturers.

The foregoing program was considered necessary, even though the investigations and test results of the large pumping units for the Metropolitan Water District of Southern California were available. No part of the research program mentioned would have been effective in detail without the development of Cal Tech Hydraulic Machinery Laboratory, with its precision instruments and exact measurements to aid in securing the effect of small design changes.

The final specifications called for a minimum flow rate of 1350 cfs at a rated total dynamic head of 310 ft. and a minimum warranted pump efficiency of 87% at this point. Furthermore, the specifications require a minimum flow rate of 800 cfs at a total dynamic head of 365 ft. and a maximum load not to exceed 65,000 HP at 270 ft. total dynamic head. The great variations of head and flow rate had to be obtained at a constant speed of 200 rpm. The specifications also prescribe that the head-capacity curve shall be relatively steep, and the pump efficiency as high as possible over the entire range of operation. The pump shall have stable operation free from cavitation within the full range of operating heads.

Each pumping unit will pump through separate piping systems. Each system consists of the trash rack, intake structure, a 90 ft. long, 14 ft. diam. suction pipe and elbow, and an 850 ft. long, 12 ft. diam. discharge pipe. The water surface at the intake to the pumping plant fluctuates from a maximum elevation of 1290 to a minimum of 1208, that is, a total difference of 82 ft. At the same time, the water surface at the outlet varies between the elevations of 1571 and 1557, a difference of 14 ft.

The foregoing head variations, and the pipe friction loss, also, the static water-surface elevation from the intake to the outlet lead to a variation of total dynamic heads from a minimum of 270 ft. to a maximum of 365 ft., or an operating range from 100 to 135 per cent. The most severe suction conditions occur at low capacities, when the water surface at the intake is at an elevation of 1208. The centerline of the pump is located at an elevation of 1203, which provides only a five-foot submersion for pumping heads from 365 ft. down to 350 ft.

Fig. 9A. 1 - Grand Coulee Dam

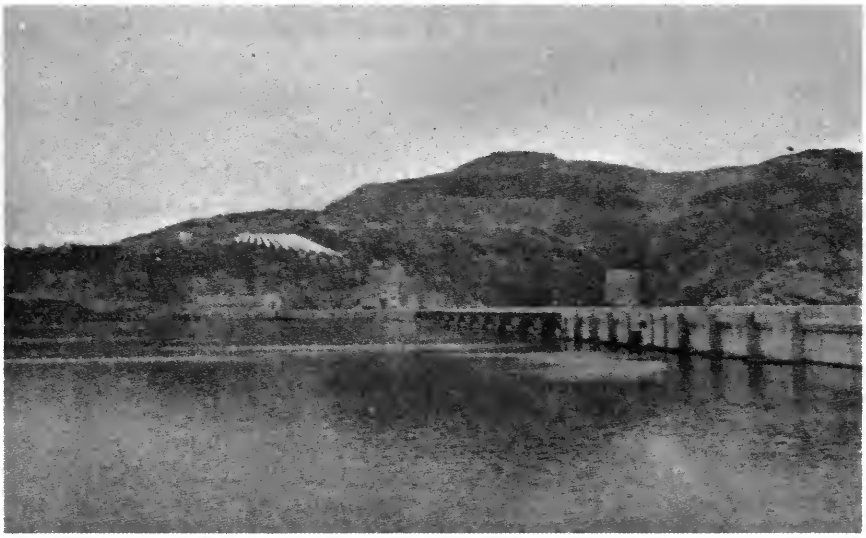


Fig. 9A. 2 - Roosevelt Lake with Pumping Plant in the background

Fig. 9A. 3 - Grand Coulee Dam and Penstocks of Pumping Plant

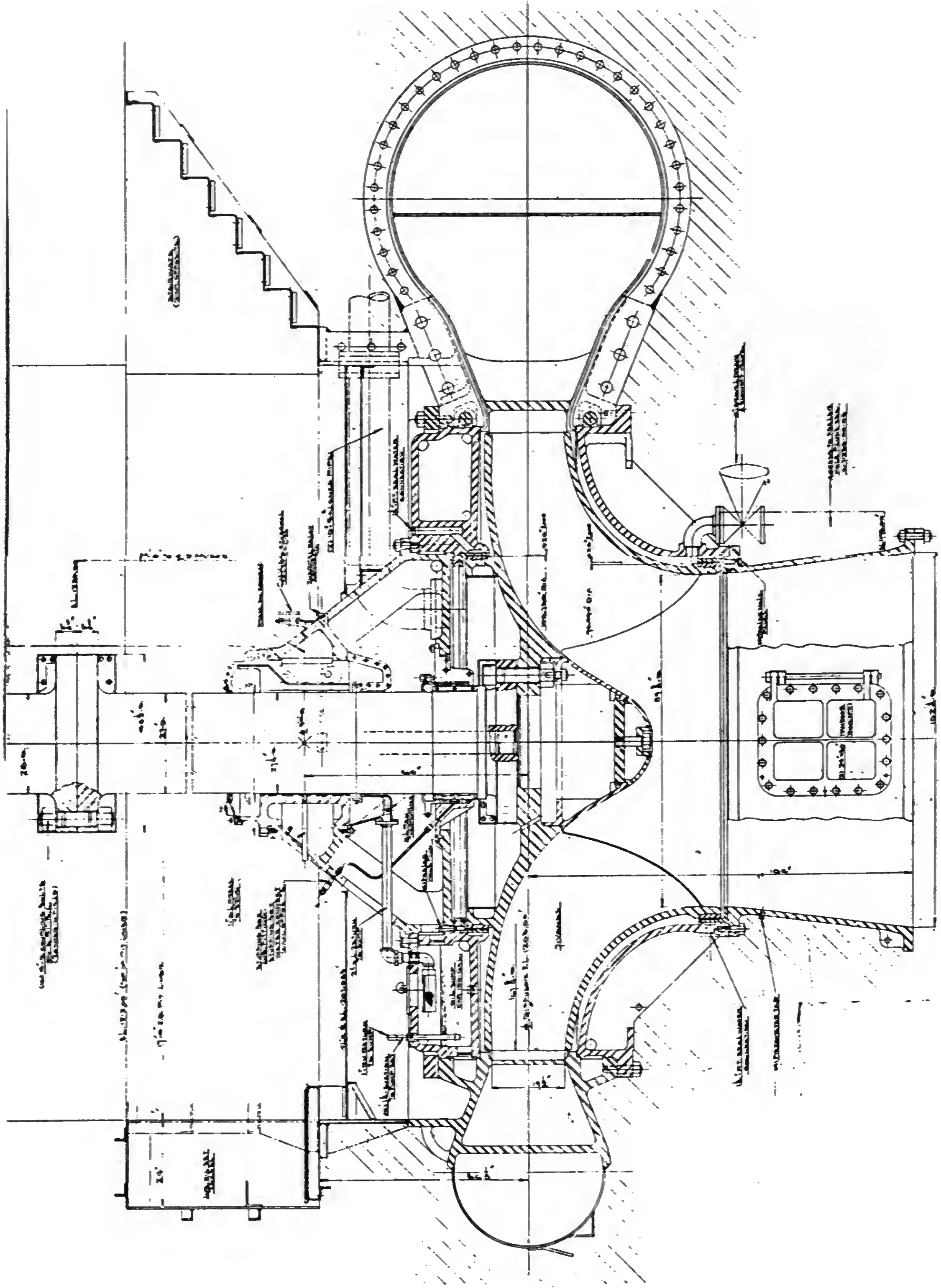


FIG. 9A-4 Cross Section of Grand Coulee Pump

| | |
|---|---|
| PLANT NAME: | BUCHANAN DAM |
| REPORT NO.: | 10A |
| LOCATION-ALTITUDE: | Central Texas - 884' |
| OWNER: | Lower Colorado River Authority (State of Texas) |
| ADDRESS: | Austin, Texas |
| TYPE OF PLANT: | Surface |
| SERVICE | Power Generation - Pump Storage |
| TYPE OF WATER: | Tail water from dam - sometimes turbid |
| UNITS INSTALLED: | One - Vertical, Single-Stage, Single-Suction, Pump-Turbine Unit |
| HORSEPOWER: | 13,450 (163.6 RPM) |
| CFS: | 835 |
| STATIC HEAD: | 131' (Max.) |
| PLANT STARTED: | 1950 |
| VISITED BY: | Hall |
| DATE: | December 8, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | Mr. V. N. Collins, Plant Superintendent<br>Mr. Gordon, Sr. Design Engineer |
| REMARKS: | Pump storage plant pumps. Water from Inks Dam reservoir back into Buchanan Reservoir. |

PUMPS:

| | |
|---|---|
| TYPE: | Vertical, Single-stage, Single-Suction |
| MANUFACTURER: | Westinghouse |
| SIZE DISCHARGE: | 84" |
| SIZE SUCTION: | 76" |
| RPM: | 163.6 |
| CFS: | 835 |
| HEAD: | 120 (Head varies from 38' to 138') |
| H.P. REQUIRED: | 13,250 |
| N s.: | 2775 |
| INSTALLED: | 1950 (Sept.) |
| HRS. OF OPERATION | 1950-54 - 524 hours/year (less since total approximately 4500 hours) |
| MIN. SUBMERGENCE: | - |
| NORMAL SUBMERGENCE: | 5' |
| MAX. SUBMERGENCE: | - |
| REMARKS: | Pump is a duplicate of Tracy pumps except for a slight change in impeller diameter. |

EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | Unknown |
| MODEL ACTUAL: | " |
| PROTOTYPE-GUARANTEED: | 88 |
| PROTOTYPE-ACTUAL: | 86.3 (Pump and Motor) |
| METHOD OF TEST: | Gibson Co. of Niagara tested plant. A model was used. |

CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 84" |
| DIAMETER IMPELLER: | 120" $\pm$ |
| DIAMETER EYE: | 24" |
| DIAMETER SHAFT: | 20" |
| MATERIAL CASING: | Cast Steel |
| MATERIAL IMPELLER: | Bronze |
| MATERIAL IMPELLER RINGS: | Bronze |
| MATERIAL-CASING RINGS: | Bronze |
| RADIAL CLEARANCE: | .044" |
| MATERIAL BALANCING RINGS: | - |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | None |
| BEARING: | 20" |
| THRUST BEARING: | - |

| | |
|---|---|
| TYPE OF PACKING: | 8 rings of 3/4" packing |
| MATERIAL OF PACKING: | - |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Synchronous - Vertical 80% |
| MANUFACTURER: | Westinghouse |
| H.P.: | 13,450 |
| R.P.M.: | 163.6 (Runaway 210) |
| VOLTAGE: | 6900 |
| STARTING: | Synchronous from standstill with other Turbine. |
| REMARKS: | Has been started across-the-line. No unwatering. |

TURBINE:

| | |
|---|---|
| TYPE: | Vertical - Francis |
| MFG.: | - |
| HEAD: | - |
| R.P.M.: | 171.4 |
| H.P.: | 17,300 |
| REMARKS: | - |

## VALVES:

### INTAKE:

| | |
|---|---|
| TYPE: | Sliding Gate |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | - |

### DISCHARGE:

| | |
|---|---|
| TYPE: | Butterfly |
| MANUFACTURER: | S Morgan Smith (A C ) |
| SIZE: | 84" |
| OPERATION: | DC Motor |
| OPENING: | " |
| CLOSING: | " |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | 2 minutes |
| REMARKS: | - |

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | - |
| NO. & SIZE: | One 12' |
| LENGTH: | Short - through dam only |

| | |
|---|---|
| MATERIAL: | - |
| TYPE OF UPPER GATE: | Sliding Gate |
| SURGE TANK: | None |
| REMARKS: | - |

WATER QUALITY:

| | |
|---|---|
| GENERAL: | Generally good - sometimes turbid |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | - |

MAINTENANCE AND OPERATION:

| | |
|---|---|
| OPERATING SCHEDULE: | During dry periods |
| STARTS/DAY: | Once per day in Season |
| HOURS OF OPERATION: | Approx. 4,500 |
| UNPLANNED OUTAGES: | None |
| CAUSE: | - |
| INSPECTION SCHEDULE: | - |
| TIME REQUIRED: | - |
| OVERHAUL SCHEDULE: | Never overhauled |
| TIME REQUIRED: | - |
| IMPELLER CAVITATION: | - |

| | |
|---|---|
| SEAL RING WEAR: | - |
| NOISE LEVEL-START: | - |
| NOISE LEVEL-RUN: | - |
| VIBRATION: | - |
| REMARKS: | Pump has not been operated for sometime. |

## GENERAL REMARKS

Buchanan Plant operates in a similar manner to any other hydro plant during peak hours, i. e., water is released from Buchanan Lake through the turbines to generate the electric power and energy required from this plant. This water flows into Inks Lake where a portion is used to operate the Inks Plant and the remainder is used to replenish the amount previously removed by pump operation.

During off-peak hours when steam energy is available the pump is started in the following manner:

The armature circuits of the generator and motor are connected and full field applied to both units. The turbine gates are gradually opened causing the generator to come to synchronous speed. The motor is accelerated to normal speed by the synchronous torque developed. All of this is done with the butterfly valve closed. After the generator and motor are brought to synchronous speed, the two units are synchronized with the remainder of the system and load applied to the motor by opening the butterfly valve. The generator is then shut down as the power and energy requirements of the motor are supplied from steam generating sources.

Careful consideration was given to specify material that would reduce operating and maintenance expense. Stainless steel was specified for the turbine on areas where cavitation may occur. Bronze was specified for the pump impeller.

Across-the-line line starting of the motor was first considered but abandoned in favor of the method described above for fear that voltage fluctuations would occur on the system during starting of motor.

The pump has been in operation since September 25, 1950, and no serious operating problems have arisen. The motor of the butterfly valve is supplied D. C. current from the station battery to assure closing of the butterfly valve in case of power failure. They are considering installing an A. C. motor on the same shaft so that the valve will be closed by A. C. unless there is a failure in the station service. The station battery would be relieved of this duty except in emergencies.

An interesting operation feature developed on December 24, 1950 when an exciter and field failure caused a complete shut-down of Inks Plant for a period of six weeks thereafter. (Inks Plant has only one generator). By careful operation of the pumping unit at Buchanan during every hour that steam energy from any source was available and through reduced operation of the Buchanan generating units no water went over the spillway at Inks during this period.

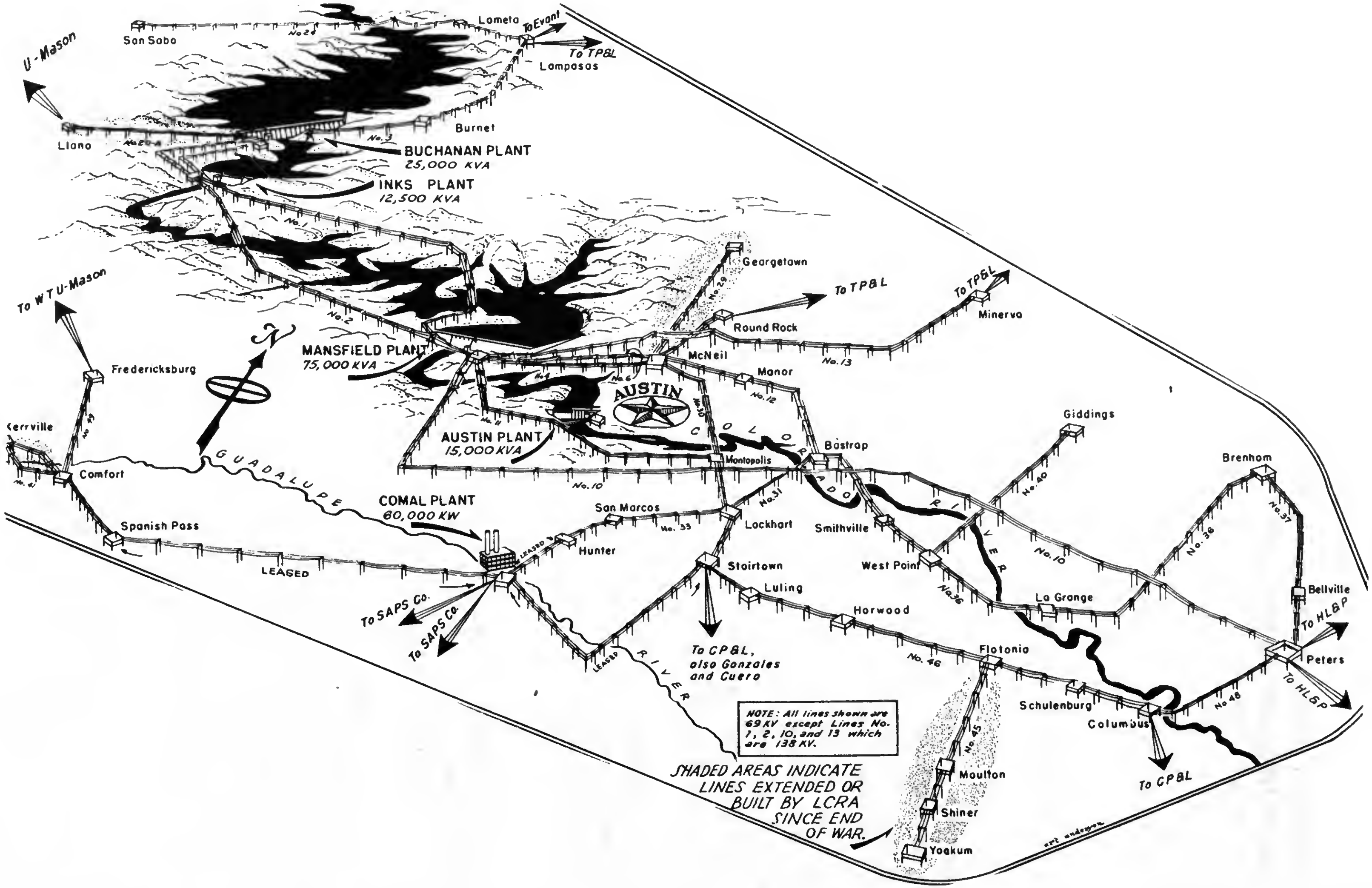
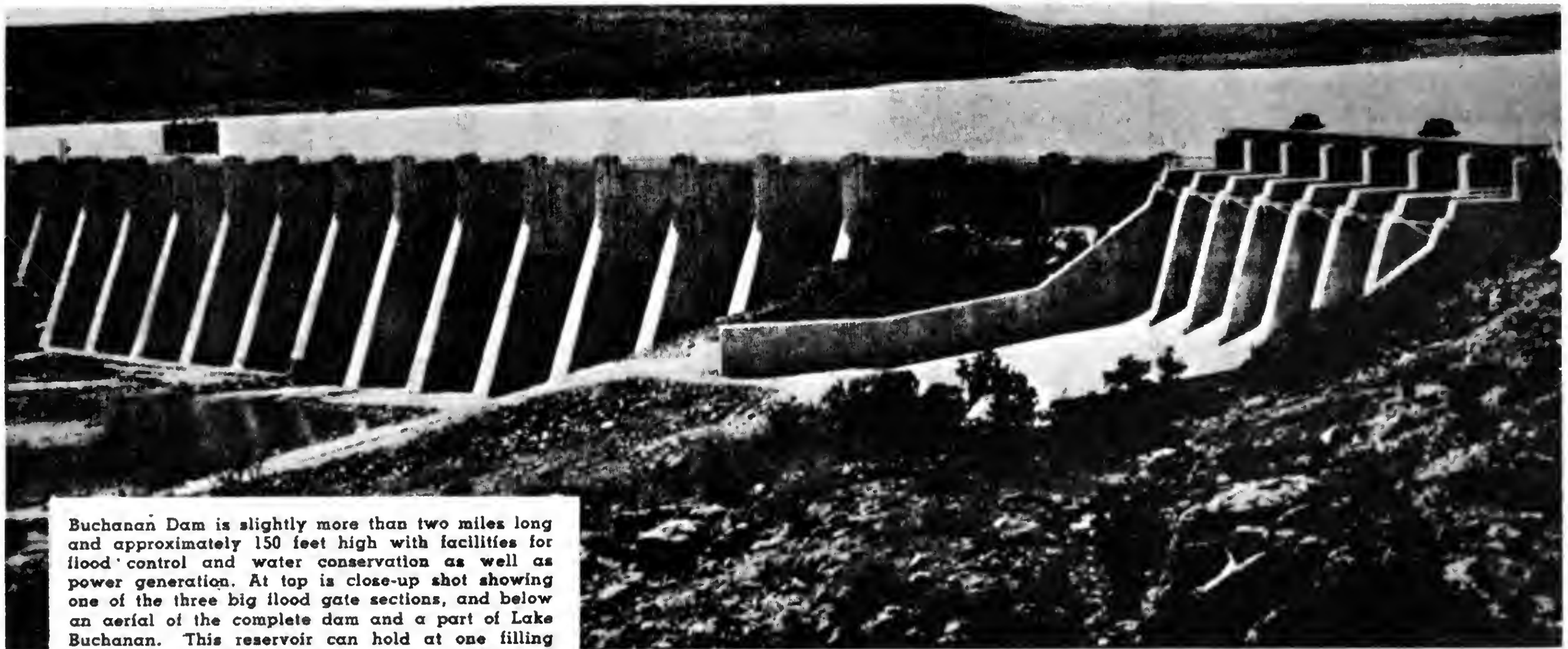



Fig. 10A-1 Plan of Lower Colorado River System



Buchanan Dam is slightly more than two miles long and approximately 150 feet high with facilities for flood control and water conservation as well as power generation. At top is close-up shot showing one of the three big flood gate sections, and below an aerial of the complete dam and a part of Lake Buchanan. This reservoir can hold at one filling sufficient water to meet needs of city the size of Houston for 18 years

Fig. 10A-2 - View of Buchanan Dam

PLANT NAME: TAUM SAUK

REPORT NO.: 11A

| | |
|---|---|
| LOCATION-ALTITUDE: | 90 MI. S. W. OF ST. LOUIS - 767' |
| OWNER: | UNION ELECTRIC CO. |
| ADDRESS: | St. Louis, Missouri |
| TYPE OF PLANT: | Pump Storage - Surface |
| SERVICE | Power Generation for Utility |
| TYPE OF WATER: | Good |
| UNITS INSTALLED: | Two single-stage, single-suction, reversible pump -Turbine units. |
| HORSEPOWER: | 250,000 (Pumps) |
| CFS: | 2450 |
| STATIC HEAD: | 863' (Max.) |
| PLANT STARTED: | 1963 |
| VISITED BY: | H. Gartmann |
| DATE: | May 13-14, 1964 |
| PERSON(S) INTERVIEWED & TITLE(S): | B. M. Carothers, Chief Engineer<br>Chas. Eichelberger, Plant Superintendent<br>H. H. Hellman, Engineer |
| REMARKS: | Purely a regeneration plant. Motors above pumping plant with weatherproof housings. |

PUMPS:

| | |
|---|---|
| TYPE: | Single-stage, Single-suction, Vertical |
| MANUFACTURER: | Allis-Chalmers |
| SIZE DISCHARGE: | 108" |
| SIZE SUCTION: | - |
| RPM: | 200 |
| CFS: | 2450 |
| HEAD: | 810 |
| H.P. REQUIRED: | 247, 500 |
| N s.: | 1390 |
| INSTALLED: | 1963 |
| HRS. OF OPERATION | Unknown (relatively few) |
| MIN. SUBMERGENCE: | 30' |
| NORMAL SUBMERGENCE: | 31' |
| MAX. SUBMERGENCE: | - |
| REMARKS: | - |

## EFFICIENCIES:

| | |
|---|---|
| MODEL GUARANTEE: | - |
| MODEL ACTUAL: | - |
| PROTOTYPE-GUARANTEED: | - |
| PROTOTYPE-ACTUAL: | 91.0% |
| METHOD OF TEST: | - |

## CONSTRUCTION DETAILS:

| | |
|---|---|
| DIAMETER DISCHARGE: | 108" |
| DIAMETER IMPELLER: | Approx. 260" |
| DIAMETER EYE: | - |
| DIAMETER SHAFT: | 48" |
| MATERIAL CASING: | T-1 Welded Steel |
| MATERIAL IMPELLER: | Steel |
| MATERIAL IMPELLER RINGS: | - |
| MATERIAL-CASING RINGS: | - |
| RADIAL CLEARANCE: | 0.035" |
| MATERIAL BALANCING RINGS: | - |
| MATERIAL INTERSTAGE SEAL: | None |
| RADIAL CLEARANCE: | - |
| MATERIAL DIFFUSER: | None |
| BEARING: | - |
| THRUST BEARING: | In Motor |

| | |
|---|---|
| TYPE OF PACKING: | Adjustable |
| MATERIAL OF PACKING: | Asbestos |
| MATERIAL OF SLEEVE: | - |
| CLEARANCE: | - |
| REMARKS: | - |

MOTOR OR GENERATOR:

| | |
|---|---|
| TYPE: | Vertical Synchronous |
| MANUFACTURER: | General Electric |
| H. P. | 240,000 (235 MW) |
| RPM: | 200 |
| VOLTAGE: | 13,800 |
| STARTING: | Induction Motor |
| REMARKS: | Pump unwatered, wickets closed. |

TURBINE:

| | |
|---|---|
| TYPE: | Reversible, pump-turbine |
| MFG: | Allis-Chalmers |
| HEAD: | 745 |
| RPM: | 200 |
| H. P.: | 240,000 |
| REMARKS: | - |

## VALVES:

### INTAKE:

| | |
|---|---|
| TYPE: | Gate |
| MANUFACTURER: | - |
| SIZE: | - |
| OPERATION: | - |

### DISCHARGE:

| | |
|---|---|
| TYPE: | Spherical |
| MANUFACTURER: | Allis-Chalmers |
| SIZE: | 108" |
| OPERATION: | |
| OPENING: | Oil-Hydraulic |
| CLOSING: | " " |
| TIME OF CLOSING: | |
| NORMAL: | - |
| EMERGENCY: | - |
| REMARKS: | Spherical valve jammed on original start-up. Now okey. |

## PENSTOCK:

| | |
|---|---|
| SURFACE OR UG. | Underground |
| NO. & SIZE: | One - 13.5'018.5' |
| LENGTH: | 185' into horizontal lined tunnel - 1332'-18.5'- then 4756'. Unlined 5.7% inclined tunnel, 25.5' x 25.5'; then into vertical shaft 27'2" shaft - 431' into reservoir. |

| | |
|---|---|
| MATERIAL: | Lined Part T-1 Steel |
| TYPE OF UPPER GATE: | None |
| SURGE TANK: | None |
| REMARKS: | - |

| | |
|---|---|
| WATER QUALITY: | Good |
| GENERAL: | - |
| Ph: | - |
| HARDNESS: | - |
| REMARKS: | - |

<u>MAINTENANCE AND OPERATION:</u>

| | |
|---|---|
| OPERATING SCHEDULE: | Generate by day - Pump by night |
| STARTS/DAY: | (One) |
| HOURS OF OPERATION: | No Record |
| UNPLANNED OUTAGES: | - |
| CAUSE: | - |
| INSPECTION SCHEDULE: | None Established |
| TIME REQUIRED: | - - |
| OVERHAUL SCHEDULE: | None Established |
| TIME REQUIRED: | - - |
| IMPELLER CAVITATION: | None |

| | |
|---|---|
| SEAL RING WEAR: | None |
| NOISE LEVEL-START: | - |
| NOISE LEVEL-RUN: | - |
| VIBRATION: | Yes |
| REMARKS: | Initial vibration, caused by harmonics in drain line.<br><br>Corrected by blocking one drain.<br><br>Plant not operated enough to obtain operating experience. |

## GENERAL REMARKS

The Taum Sauk Project is located about 75 miles southwest of St. Louis on the East fork of the Black River. The two huge pump-turbine units rank among the largest Francis type ever built. Each of these units is rated 240,000 hp as a turbine under 745 ft. head, and with a capacity of 2450 cfs against a total of 810 feet as a pump. The power for driving these units as motor driven pumps is transmitted approximately 60 miles to Taum Sauk from the Union Electric Company's steam plants.

This project is an example of a true regenerative plant. The recycling process utilizes a dam-contained lower pool at the river fork and an upper reservoir that is quarried into the top of a nearby mountain. The flow from both the Black River and Taum Sauk Creek was used initially to fill the lower pool, and subsequently only to make up for evaporation losses. A 26-ft. diameter, 6800 ft. long tunnel and steel Y branch penstock connects the pump-turbines to the reservoir.

The Francis type sectionalized impeller-runners are estimated to weigh approximately 150 tons each, and compare in diameter with the Hiwassee runner. The all-welded spiral cases are designed for fabrication of "T-1" plate steel. Each turbine inlet is provided with a 9' spherical valve.

The project was not completed in time for the 1963 Summer peak, and 1964 peaks were not reached at the time of the inspection. Therefore, the plant has had very little operating experience.

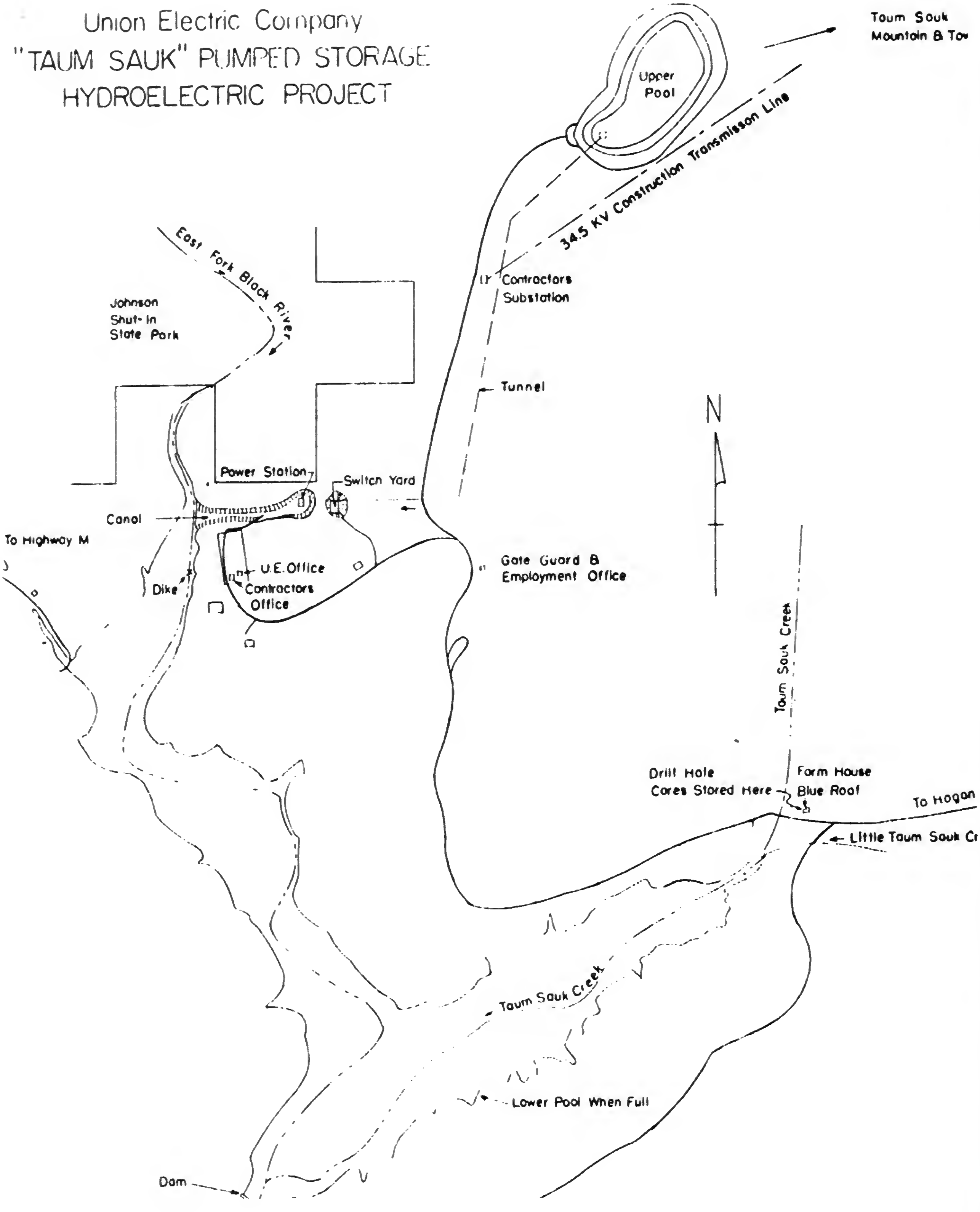



Fig. 11A-1 - Plan of Taum Sauk System

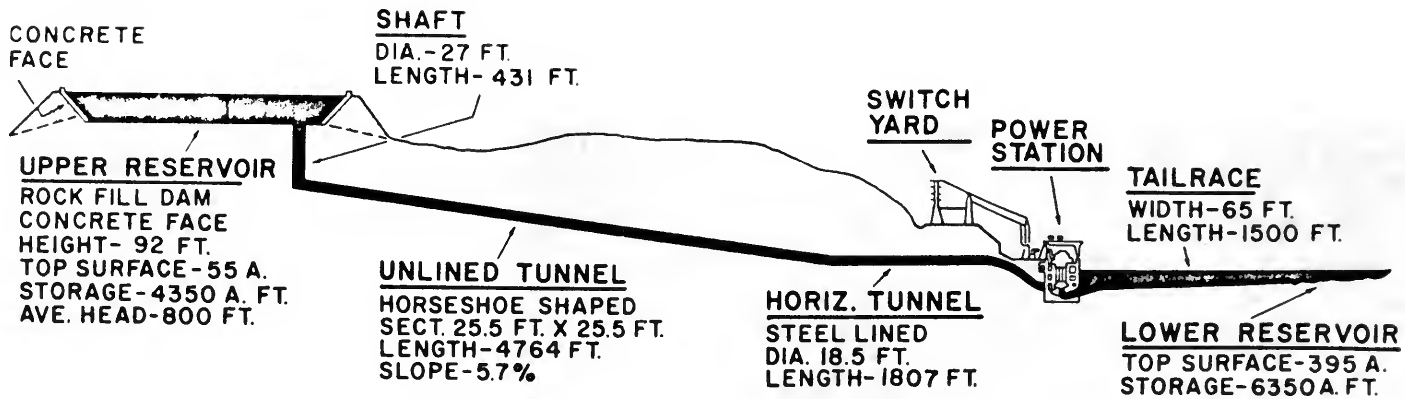



Fig. 11A-2 - Profile of Taum Sauk System

Power station equipment arrangement

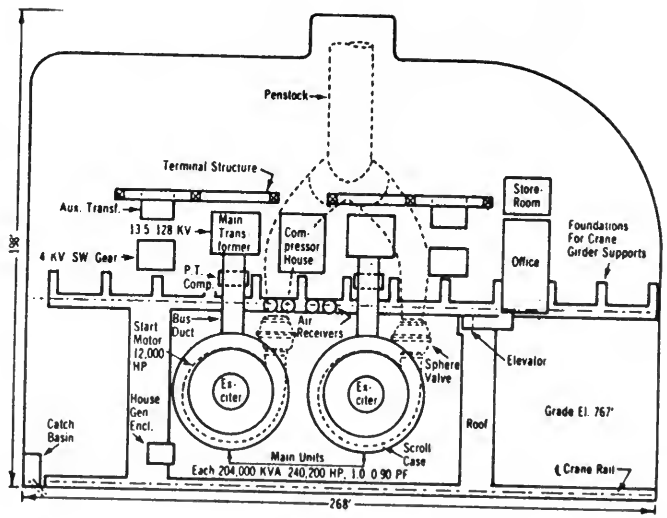



Fig. 11A-3 - Plan of Station.

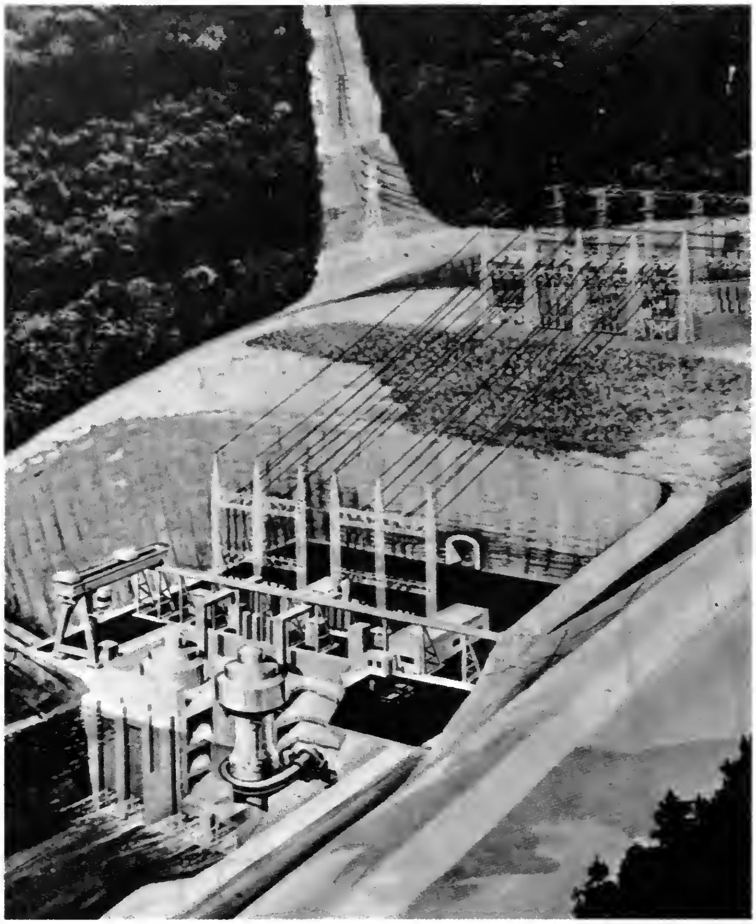


Fig. 11A-4 - Station Arrangement

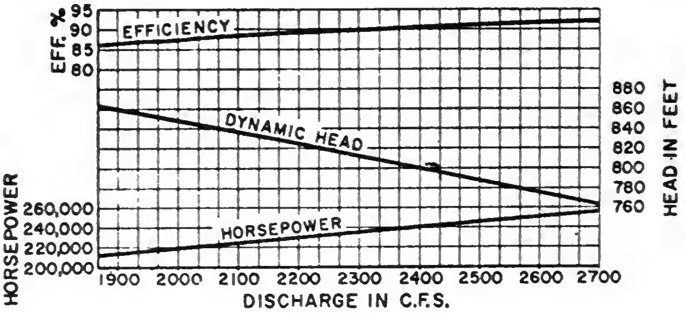



Fig. 11A-5 - Characteristic Curve of Pump

# APPENDIX

## SUMMARY OF PUMPING PRACTICE

| | |
|---|---|
| Comparison - Tehachapi with European Installations | Plate I |
| Comparison - Tehachapi with American Installations | Plate II |
| Summary of Data | Plate III |
| Summary of Data | Plate IV |
| Summary of Data | Plate V |

---

Plates I through V are bound following Chapter 2 in Volume II

---